TM 9-5000-13

DEPARTMENT OF THE ARMY TECHNICAL MANUAL

NIKE I SYSTEMS
NIKE I COMPUTER
SAM PROBLEM ANALYSIS
SERVO LOOP ELEMENTS
AND POWER DISTRIBUTION
(U)

DEPARTMENT OF THE ARMY • MAY 1956

By Order of *Wilber M. Brucker*, Secretary of the Army:

MAXWELL D. TAYLOR,
General, United States Army,
Chief of Staff.

Official:
JOHN A. KLEIN,
Major General, United States Army,
The Adjutant General.

Distribution:
Active Army:
Tec Svc, DA (1) except COFORD (7)
Ord Bd (2)
Army AA Comd (2)
Ord Ammo Comd (1)
OS Maj Comd (2)
Log Comd (3)
MDW (1)
Armies (3)
Arty & GM Sch (5)
AAA & GM Sch (1500)
Ord Sch (5)
Ord GM Sch (100)
AAA & GM Cen (7)
Ord Sec, Gen Depots (5)
Ord Depots (5)
Ord PG (10)
Ord Arsenals (2) except
Raritan Arsenal (13)
Frankford Arsenal (7)
Fld Comd, AFSWP (1)
Units organized under following TOE's:
9–228R, Ord GM DS Co (CPL) (Tentative) (1)
9–229R, Ord GM DS Co (NIKE) (Tentative) (3)
NG: None.
USAR: None.
For explanation of abbreviations used, see SR 320–50–1.

WARNING NOTICES

Authority for release of this document to a foreign government must be secured from the Assistant Chief of Staff, Intelligence, Department of the Army.

When this document is released to a foreign government, it is released subject to the following conditions: This information is furnished with the understanding that it will not be released to another nation without specific approval of the United States of America, Department of the Army; that it will not be used for other than military purposes; that individual or corporation rights originating in the information whether patented or not will be respected; and that the information will be afforded substantially the same degree of security as afforded by the United States of America, Department of the Army.

This document contains information affecting the national defense of the United States within the meaning of the Espionage Laws, Title 18 U. S. C., sections 793 and 794. The transmission or the revelation of its contents in any manner to an unauthorized person is prohibited by law.

U. S. GOVERNMENT PRINTING OFFICE: 1956

DEPARTMENT OF THE ARMY
WASHINGTON 25, D. C., *15 May 1956*

TM 9-5000-13, Nike I Systems, Nike I Computer, Sam Problem Analysis, Servo Loop Elements, and Power Distribution (U), is published for the use of all concerned.

The special texts in the TM 9-5000-series are training supplements to those in the TM 9-5001-series which are the basic Army directives for the operation and maintenance of the Nike I Guided Missile System. In the event of conflict, technical manuals in the basic TM 9-5001-series will govern.

[AG 413.44 (10 May 56)]

By Order of *Wilber M. Brucker*, Secretary of the Army:

MAXWELL D. TAYLOR,
General, United States Army,
Chief of Staff.

Official:
JOHN A. KLEIN,
Major General, United States Army,
The Adjutant General.

DISTRIBUTION:
Active Army:
Tec Svc, DA (1) except COFORD (5)
Ord Bd (2)
Hq CONARC (3)
Army AA Comd (2)
Ord Ammo Comd (1)
OS Maj Comd (2)
Log Comd (3)
MDW (1)
Armies (3)
1st GM Brig (35)
Ord Sch (2)
Arty & GM Sch (5)
Ord GM Sch (100)
AA & GM Cen (5)
Ord Sec, Gen Depots (5)
Ord Depots (5)
Ord PG (10)
Ord Arsenals (2)
Fld Comd, AFSWP (1)
Units organized under following TOE's:
9-228R, Ord GM DS Co (CPL) (Tentative) (1)
9-229R, Ord GM DS Co (NIKE) (Tentative) (3)
9-377R, Ord Sp Wpn Depot Co (1)
19-177R, MP Scty Co, Ord Sp Wpn Depot Bn (1)
44-112C, Hq & Hq Btry, AAA Gp, Continental (5)
44-201R, Hq & Hq Btry, AAA Brig, Continental (5)
44-445R, AAA Msl Bn, NIKE, Continental (17)

NG: None.
USAR: None.
For explanation of abbreviations used, see SR 320-50-1.

TM 9-5000-13
15 May 1956

CONTENTS

		Paragraph	Page
CHAPTER 1.	INTRODUCTION	1-3	1
CHAPTER 2.	NIKE I SAM PROBLEM		
Section I.	The surface-to-air missile problem	4-6	3
II.	Orientation of the missile	7, 8	5
III.	External guidance system	9	8
IV.	Spherical coordinates	10, 11	9
V.	Rectangular coordinates	12	9
VI.	Speed, velocity, and acceleration	13-17	12
VII.	Resolution of vectors	18, 19	15
VIII.	Reference planes and axes	20-24	17
CHAPTER 3.	DC AMPLIFIER CIRCUITRY	25-50	20
CHAPTER 4.	AUTOMATIC ZERO SETTING CONTROLS		
Section I.	Over-all purpose	51-55	40
II.	Semiprecision automatic zero set system	56-58	44
III.	Precision zero set system	59-61	47
IV.	Overload indicator	62, 63	52
CHAPTER 5.	SERVO LOOP ELEMENTS		
Section I.	Excitation voltage	64, 65	53
II.	400-cycle balanced modulator	66-74	55
III.	Low-power servoamplifier	75-80	62
IV.	Servomotor	81, 82	69
V.	Feedback generator	83, 84	71
VI.	Potentiometers	85-93	73
VII.	Spiral data potentiometers	94-98	81
VIII.	Quadrant switching	99-103	85
IX.	Computer servos	104-115	88

		Paragraph	Page
CHAPTER 6.	POWER DISTRIBUTION AND VOLTAGE REGULATORS		
Section I.	A-C power distribution	116-122	98
II.	D-C power distribution	123-129	101
III.	D-C voltage regulators	130-134	105
IV.	Operation	135-138	106
V.	A-C regulator GA50810	139-141	108
VI.	+S voltage regulator	142-144	109
APPENDIX			111
INDEX			118

CHAPTER 1

INTRODUCTION

1. PURPOSE AND SCOPE

a. This text presents to the reader an introduction to the SAM problem and Nike I computer methods of solving this problem along with a block diagram and detailed discussion of the electronic components used in the solution.

b. In the following pages, the SAM problem, DC amplifier circuitry, servo loop elements, and power distribution will be discussed. The block diagram discussion will precede the detailed discussion of the elements.

2. REFERENCES

References within the body of this text are found in several forms. References to other special texts will be the form "TM 9-5000-14 with the paragraph number, when appropriate. Reference to a general circuit will be of the form "TM 9-5000-26, page 162" and will refer to the page or first of several pages on which the circuit is shown. References of the form "(108 C 4)" refer to TM 9-5000-26 by page number and the zone numbering system found in TM 9-5000-26. This reference system will be used to point out specific items within a schematic. References of the form "(16C13)" refer to the sheet number and zone number system also found in TM 9-5000-26. This reference system has been avoided wherever possible.

3. REVIEW

At the close of World War II, it became apparent that development of faster and more maneuverable hostile bomber aircraft and infinitely more destructive bombs, such as the atomic bomb, made it necessary to increase the capabilities of antiaircraft artillery weapons to attack and destroy such aircraft. Two disadvantages of heavy artillery (90-mm and 120-mm guns) became apparent. These disadvantages were limited range and insufficient accuracy. The operating ceiling of present-day aircraft has increased to such an extent that airplanes may fly above the maximum effective range of heavy artillery. With the probability that hostile aircraft will carry atomic armament, it becomes even more urgent that the accuracy of heavy AAA be increased to insure the destruction of hostile aircraft before the bombs are released. A 90mm or 120mm projectile has a long and uncontrolled time of flight. Although the fire control equipment is capable of accurately predicting the point of impact, the ability of hostile aircraft to maneuver while the projectile is

in its uncontrolled flight may result in such a great miss distance that the battery will be unable to accomplish its mission. Weapons have been developed which are capable of attacking and destroying modern enemy aircraft. One of these weapons is the surface-to-air guided missile (SAM). The surface-to-air missile has an effectiveness considerably greater than heavy artillery. It has a greater range because of its motor, and is more accurate because it is guided during flight. Surface-to-air missiles are guided throughout most of their flight paths from ground to target, and are capable of outmaneuvering any present known hostile aircraft operating at medium or high altitudes. The Nike I missile is a missile of this type. During flight, the Nike is guided from the ground by a fire control system. The mathematical computations necessary for accurate guidance of the missile are performed by the computer. An improperly functioning computer cannot guide the missile accurately. This cannot be tolerated, partly because of the high cost of each wasted missile, but mainly because of the danger presented by a hostile target. To understand the necessity and the importance of the computer in the fire control system, the student must understand the problem which the computer must solve.

CHAPTER 2

NIKE I SAM PROBLEM

Section I. THE SURFACE-TO-AIR MISSILE PROBLEM

4. GENERAL

The surface-to-air missile problem is to guide a missile launched from the ground so that it will arrive and burst in the sky close enough to a target at the time of burst to destroy it. The steps in the solution of this problem depend upon the weapon to be used and upon the type of guidance system chosen to guide the missile.

5. COMMAND GUIDANCE

In the Nike I system, the direction of flight of the missile is controlled by the computer. The computer-controlled flight starts about 7 seconds after the missile is fired and ends with the burst of the missile after a burst order has been issued by the computer through the missile-tracking radar. The two tracking radars keep the computer continuously informed about the present positions of target and missile. Through the missile-tracking radar, the computer issues directional commands to make the missile intercept the target in the shortest possible time. Guiding a missile by ordering it to change its direction of flight is command guidance. The surface-to-air command guidance problem can be summed up by the following question. Knowing the present position of target and missile, and knowing also where target and missile have been, what directional order should be issued to the missile at the moment to cause interception in the shortest possible time? In the formulation of the command guidance problem, past position data must be taken into account. Knowledge of present positions alone would be insufficient for steering the missile. It is not enough to know where the target is at the moment; the computer must also know where the target is going and how fast it is going there. Thus, the course of the target and missile can be predicted and their interception under these circumstances can be determined. Should they not intercept, this future prediction tells how to rectify the missile course. To tell the direction and speed at which an object is moving, it is necessary to observe it for a short time and remember where it has been. Therefore, the computer needs a memory. This is also the reason why the computer is not ready to issue orders as soon as the target is picked up by the target-tracking radar. It must receive and remember position data for 4 seconds until it knows exactly the direction and speed of the motion involved. The memory of the computer lies in its differentiating circuits. The computer has no control over the speed of the

missile. It can tell the missile to turn right or left, up or down, but it cannot tell the missile to go faster or slower. Therefore, the uncontrolled quantities are missile speed and target direction and speed. From these, knowing missile and target present positions, the computer must find the correct missile course (direction of flight), and must determine the appropriate fin orders to bring the missile onto this correct course. This course will be correct only as long as the direction of flight and speed of the target do not change. If the target maneuvers, the correct course for the missile changes continuously and the computer must issue continuous steering orders to keep the missile as close as possible to the correct course.

6. THE INTERCEPT COURSE

When the direction of flight and the speed of the missile, as well as the present position of target and missile is known, in which direction should the missile be moving so that it will approach the target as rapidly as possible? This question falls into the general study of pursuit curves. At first, it may seem that the correct course would be for the missile to fly so that it points directly at the target. A pursuit based on this simple rule generates a curve known as a dog curve, because that is roughly the path a dog follows when chasing a rabbit. Such a pursuit curve places minimum requirements on the intelligence of the steering apparatus (ground control), and is used by a class of missiles that operate on the homing principle. A missile flying a dog curve takes longer to intercept a moving target than a missile flying a more advantageous course. As a result, a target might escape the range of the guidance equipment, even though it may have been intercepted if a pursuit curve with a faster rate of approach were used. It is quite plausible that the pursuit time can be reduced by heading off the target; that is by flying the missile towards a point which is ahead of the target. This is what an AA projectile does when it is fired at the future position of the target in space. A pursuit curve which takes full advantage of time that can be gained by leading the target is called an intercept curve. Mathematical analysis of the pursuit problem shows that the requirement for maximum rate of approach is met by the intercept curve. The Nike I computer directs the missile so that it approaches the target along a slightly modified intercept course. Therefore, the problem solved by the Nike I computer is the determination of the correct intercept curve which the missile must follow so that the missile will arrive and burst in the sky close enough to a target at the time of burst to destroy the target.

Section II. ORIENTATION OF THE MISSILE

7. GENERAL

An elementary knowledge of the missile and its external guidance system is desirable as background information before discussing a solution to the SAM problem.

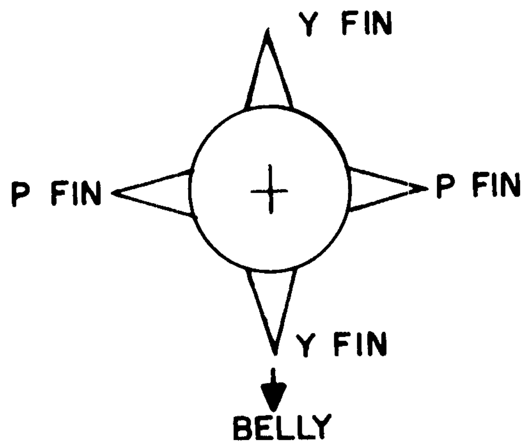


Figure 1. Rear view of the orientation of the first Nike missile.

8. THE MISSILE

The original Nike I missile was oriented as shown in figure 1. The missile was caused to turn (yaw) by applying orders to the Y-fin pair, and to dive or climb (pitch) by applying orders to the P-fin pair. This missile configuration did not permit the missile to intercept a target inside a dead zone much larger than that shown in figure 2, since the maximum dive order which could be executed was a 5g order. The dead zone was reduced to that shown in figure 2 by orienting the missile as shown in figure 3. Rotating the Y-fin pair 45° counterclockwise reduced the dead zone because the same dive order applied to each fin pair as before will result in a maximum resultant dive 1.414 times greater. For example, an acceleration order of -5g applied to the missile P-fins as shown in figure 1 will permit a maximum dive of 5g; whereas, -5g applied to each fin pair as shown in figure 3 will result in a maximum dive of $(1.414)(-5g) \approx -7g$, as shown in figure 4. Thus, the dead zone is considerably reduced. A 7g dive is the maximum dive the Nike missile can make. Fin orders to the missile are in terms of acceleration, where 5g is an order which would cause the missile to accelerate 5 times faster than the acceleration resulting from the force of gravity (g = 10.7 yards per second per second). The missile is stabilized so that it does not roll on its longitudinal axis as it travels through space. Figure 5 is an external view of the missile, showing the control fins.

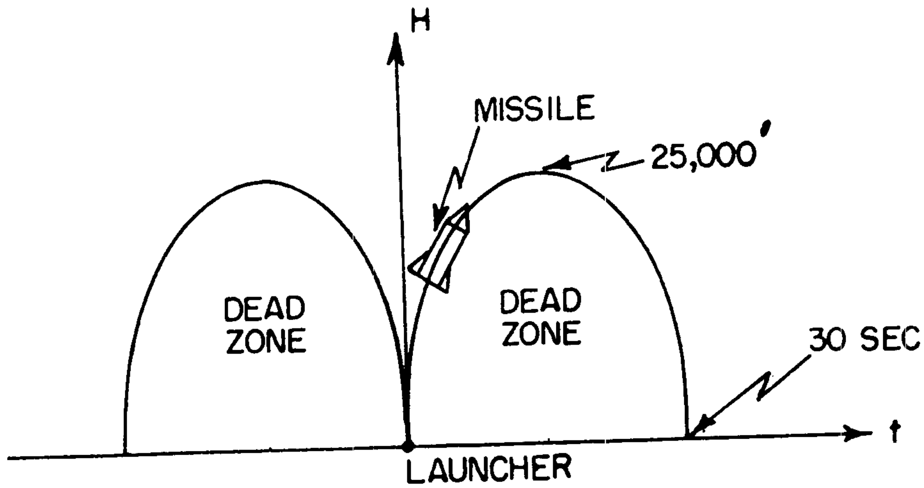


Figure 2. Intercept is impossible within the dead zone.

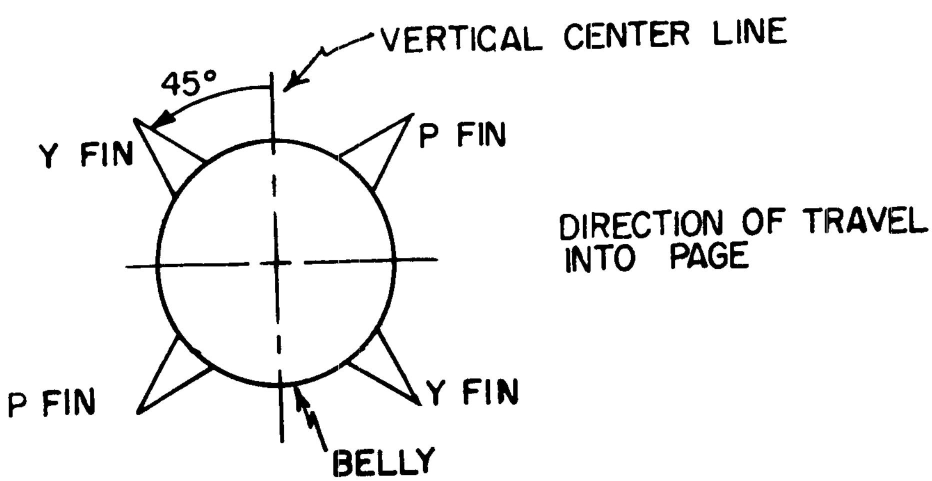


Figure 3. Orientation of the present Nike I guided missile.

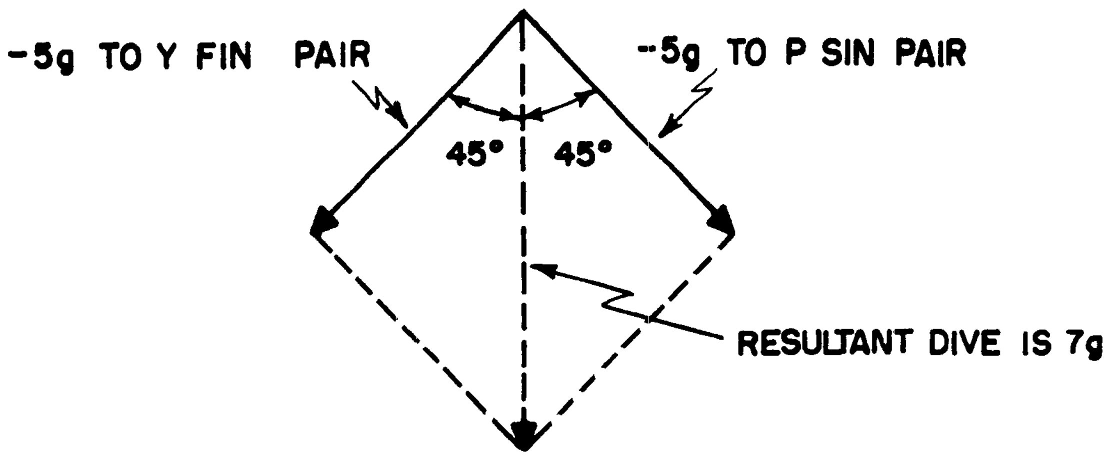


Figure 4. Resultant dive order with -5g applied to each fin pair.

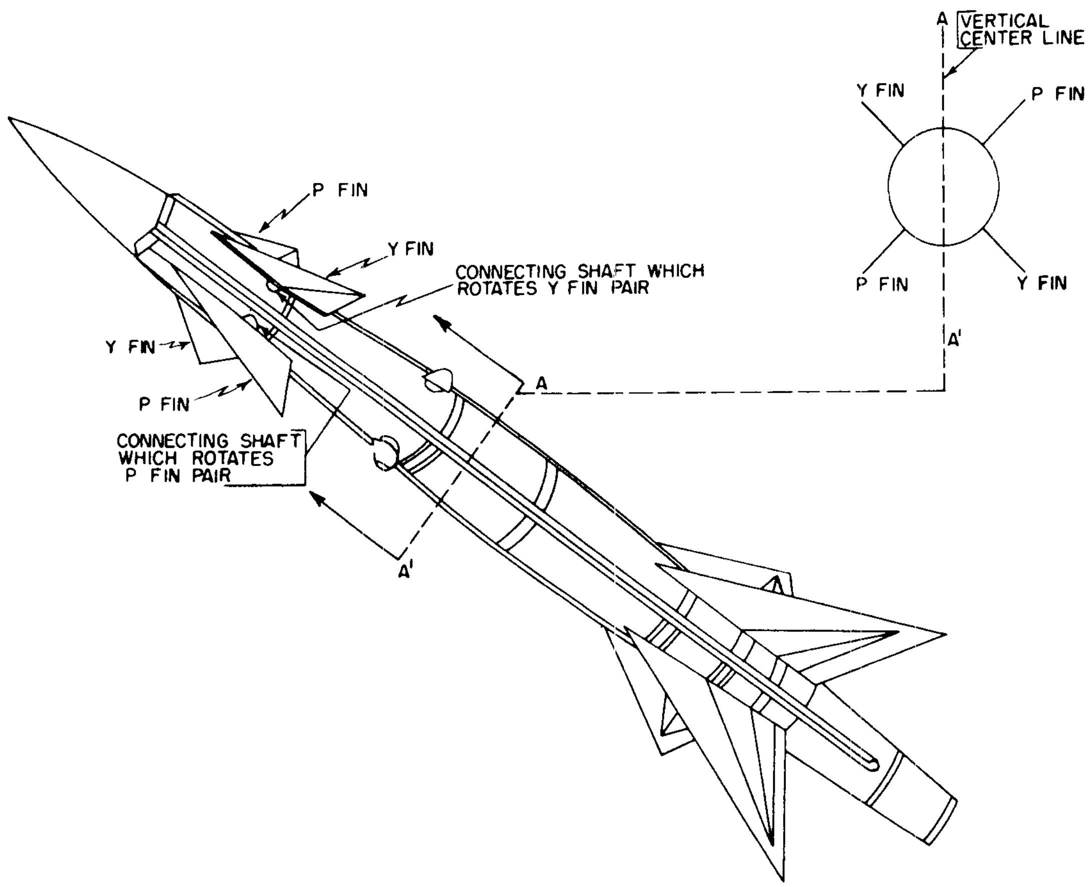


Figure 5. View of the missile showing the control fins.

Section III. EXTERNAL GUIDANCE SYSTEM

9. GYRO AZIMUTH

The Nike I missile is controlled in flight by a command guidance system. The command guidance system permits continuous correction of the missile flight path after launching. The guidance commands are computed and transmitted by the external ground guidance equipment. The Nike I computer performs the necessary mathematical calculations to determine how much lateral and vertical acceleration must be caused by each fin pair to produce a desired result. Then, suitable commands are transmitted to the missile, through the missile-tracking radar. The computer also sends a command to burst the missile. To guide the missile successfully, the commands sent to it must cause accelerations in relation to a fixed reference common to both the computer and the missile. Once the missile is launched, this fixed reference must not change regardless of the attitude of the missile. The device used to maintain this fixed reference is the roll amount gyroscope. Using the roll amount gyro for this purpose limits the amount that the missile may turn to the right or left. If the angle through which the missile turns (yaws) exceeds a certain design limit, the gyro will be forced into a condition known as gimbal lock. When the gyro is in gimbal lock, the reference no longer remains fixed, but changes whenever the missile attitude changes. Consequently, if gimbal lock occurs, the missile becomes uncontrollable. Because of this physical limitation, the computer determines the azimuth of the intercept point before the missile is launched. The computer then transmits to the missile a voltage analogous to the intercept point azimuth, which causes the plane of the roll amount gyro to be oriented in the azimuth of the intercept point. With the plane of the roll amount gyro so oriented, the missile is guided on the azimuth to the intercept point approximately 5 seconds after launch. If the target does not change its course and speed after missile launch, the angle through which the missile will turn on its way to the intercept point is quite small. Little time is lost in making such a small turn, and the time elapsed between launch and intercept is considerably reduced from the time which would elapse if the missile were required to turn through large angles. Therefore, one advantage of prelaunch determination of intercept point azimuth is the increased rate of battery fire because of the reduced launch-to-intercept time. Even if the target executes a violent evasive maneuver, the resulting angles through which the missile would have to turn will seldom, if ever, be large enough to exceed the critical angle for gimbal lock.

Section IV. SPHERICAL COORDINATES

10. GENERAL

Points on the ground and in space are located by describing the position of such points with reference to known directions or points.

11. MILITARY SPHERICAL COORDINATES

The location of a target and missile in space is determined by using the spherical coordinates commonly used by the Army. The three spherical coordinates are slant range (D), angular height (E), and azimuth (A). Figure 6 shows a target located by spherical coordinates. Target slant range, elevation, and azimuth are called D_T, E_T, and A_T, respectively. The spherical coordinates of the missile are D_M, E_M, and A_M.

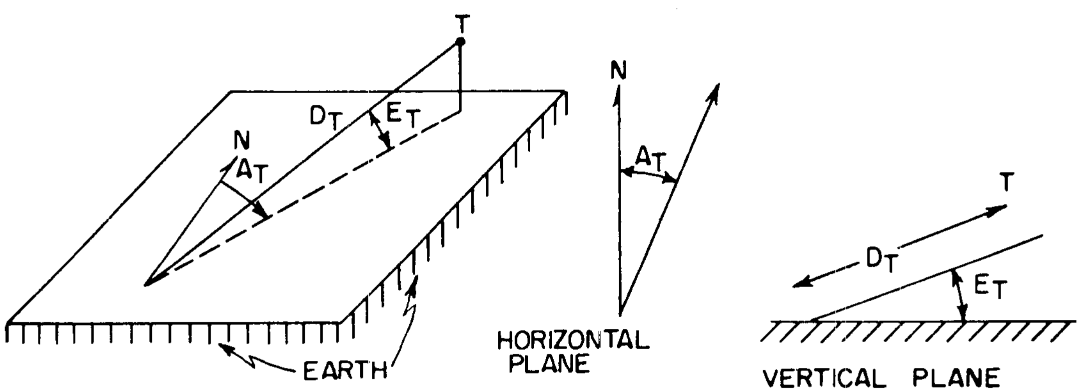


Figure 6. Locating a target by using spherical coordinates.

Section V. RECTANGULAR COORDINATES

12. MATHEMATICAL COMPUTATION

The mathematical computations which must be performed by the computer are more easily accomplished by using rectangular coordinates. For this reason, target and missile locations are converted from spherical to rectangular earth coordinates, using the Army system of reference. Military maps have horizontal and vertical grid lines. The rule for reading military maps is to read right and up. The numbers on each grid line increase when reading from left to right (west to east) and when reading from bottom to top (south to north). The most common unit of measurement in the rectangular coordinate system is the yard. The reference point in this system is

known as the origin of coordinates. In 2-dimensional rectangular coordinate systems, two lines, called axes, pass through the origin and intersect at right angles to each other. Figure 7 shows a 2-dimensional rectangular coordinate system. The horizontal and vertical axes are designated as the X and Y axes. A 2-dimensional rectangular coordinate system is contained in a plane surface. A 3-dimensional coordinate system is formed by passing an additional axis through the origin, perpendicular to the X and Y axes, and perpendicular to the plane formed by the X and Y axes. A 3-dimensional coordinate system is shown in figure 8. The axis perpendicular to the X and Y axes is designated as the H axis. The location of a target, T, in a 2-dimensional coordinate system is shown in figure 9. Point T is located by measuring its distance from the origin along the X and Y axes. The X coordinate is 4 units and the Y coordinate is 2 units. The location of a point T in a 3-dimensional coordinate system is shown in figure 10. Point T is located by measuring its distance from the origin along each of the three axes. The X coordinate is 4 units, the Y coordinate is 4 units, and the H coordinate is 2 units.

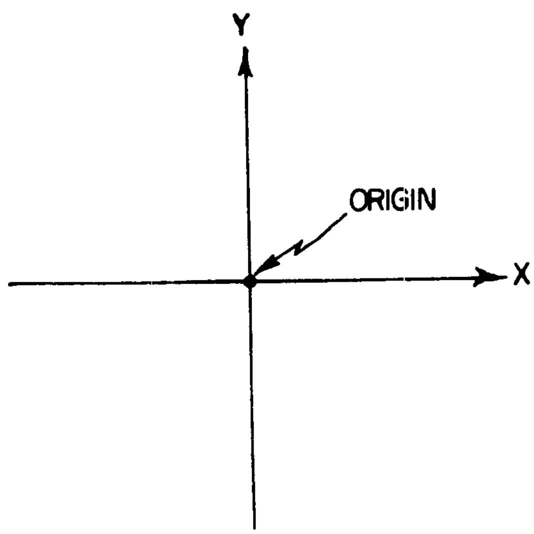


Figure 7. Two-dimensional rectangular coordinate system.

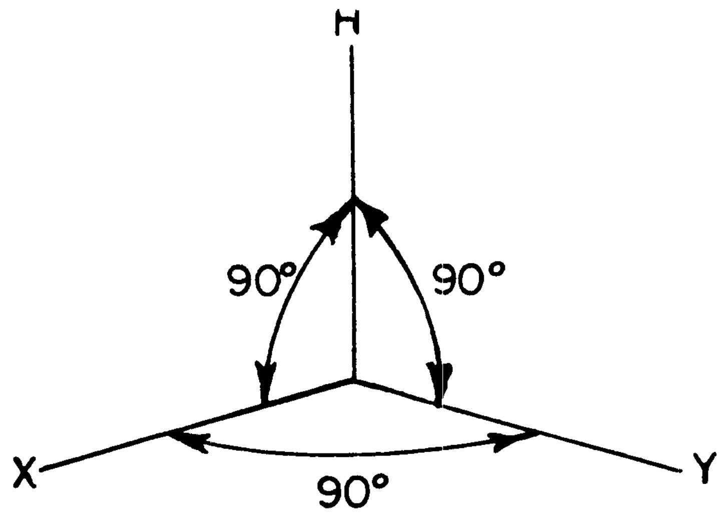


Figure 8. Three-dimensional rectangular coordinate system.

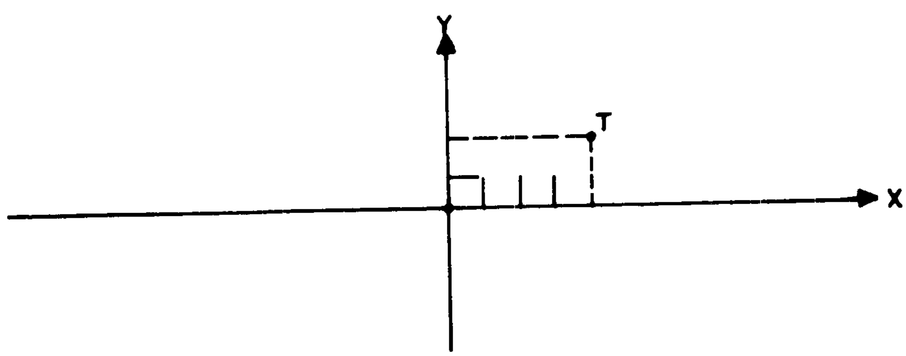


Figure 9. Location of a point in a 2-dimensional coordinate system.

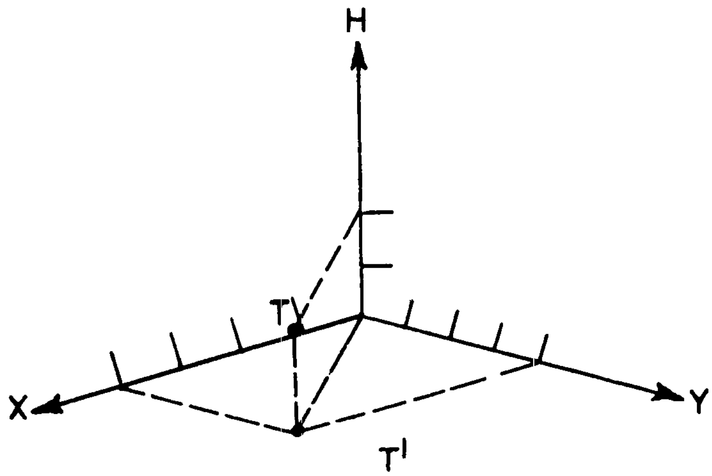


Figure 10. Location of a point in a 3-dimensional coordinate system.

Section VI. SPEED, VELOCITY, AND ACCELERATION

13. SPEED

Speed is defined as the rate at which distance changes with respect to time. Consider a sedan moving along a road. If the speedometer dial points to the number 45 the driver knows that the speed of his sedan is 45 miles per hour. In computations performed by the Nike I computer, speed is expressed in yards per second. (Conversion factor: 2 mph equals approximately 1 yd/sec.)

14. VELOCITY

The term velocity expresses both speed and direction. Velocity can be represented by a vector. If a driver in a sedan equipped with a compass is moving at a speed of 45 miles per hour as indicated by his speedometer, and at the same time his compass needle points northeast, then his sedan has a velocity of 45 miles per hour northeast. In computations performed by the computer, velocity is expressed in terms of yards per second and direction is expressed in mils measured from an established line of direction. Thus, the velocity of the sedan above is expressed as 22 yards per second, at an azimuth of 800 mils from north. A change of velocity with respect to time may imply a change in speed, a change in direction, or change in both speed and direction.

15. RECTANGULAR COMPONENTS OF VELOCITY

Many of the computations performed by the computer are made in terms of velocity expressed in rectangular components. The representation of a velocity in rectangular components requires that the vector which represents velocity be resolved (converted) into components which lie along the axes of the coordinate system being used. The process of resolving a velocity into its 2-dimensional components is shown in figure 11. The velocity produces X and Y components ($\dot{X}$ and $\dot{Y}$) of the vector V.

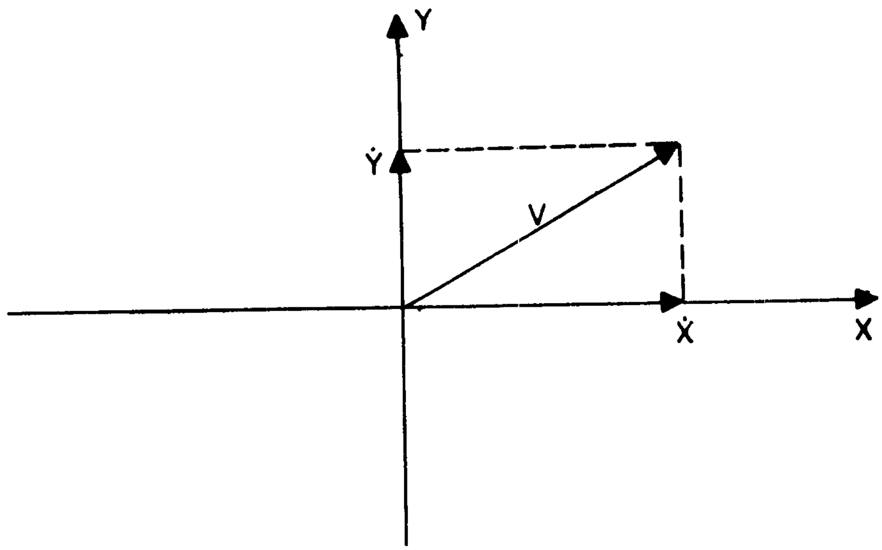


Figure 11. Resolving a vector into its rectangular components.

16. ACCELERATION

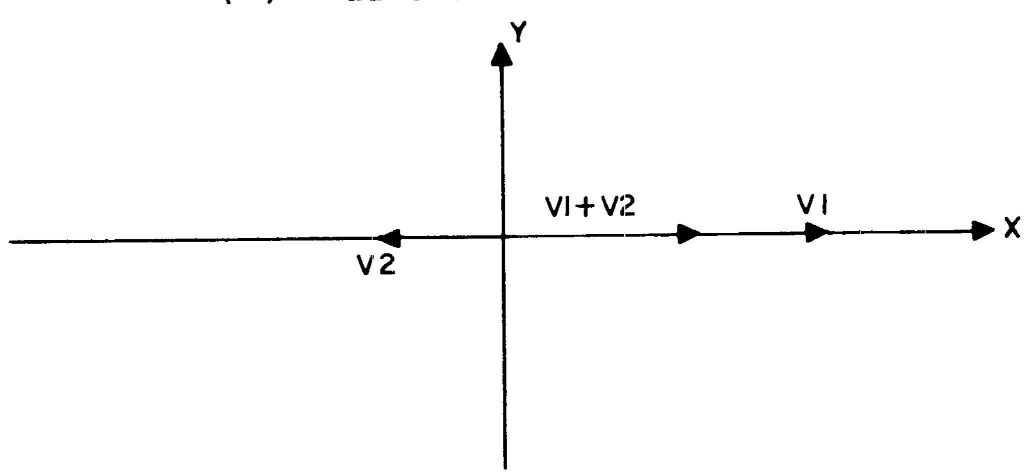
Acceleration is defined as the time rate of change of velocity. Consider the man in the sedan going 45 mph with his compass pointing northeast. If 1 hour later the speedometer indicates 50, 2 hours later it indicates 55, and 3 hours later it indicates 60, the average acceleration is 5 miles per hour per hour. Again consider the sedan traveling at 45 miles per hour with the compass indicating northeast (800 mils). If 1 minute later the compass reads east (1,600 mils), and 2 minutes later it reads southeast (2,400 mils), the average change in direction is 800 mil~~e~~s per minute. In this example, the direction associated with velocity has changed with respect to time and by definition the sedan is accelerating. This is true even though the 45-mph speed of the sedan is unchanged. The process of steering the missile during its flight consists of causing the missile to change direction while in flight. Therefore, the missile is guided by causing it to accelerate and, for this reason, the voltages produced by the computer as final outputs are expressed

in terms of acceleration. The unit used is g. It is a symbol which represents the acceleration caused by the force of gravity and is equal to 10.7 yards per second per second. For example, a missile that makes a 7g turn has an acceleration seven times greater than the acceleration caused by gravity.

17. VECTOR ADDITION AND SUBTRACTION

A review of the principles of vector addition and subtraction is necessary because the majority of the quantities developed in the computer are vector quantities. One important fact to be remembered is that on paper the arrow which represents a vector may be moved to any position as long as it is kept parallel to its original position. Two or more vectors may be added by graphically attaching the tail of one vector to the head of the other. Figure 12 illustrates this process. Vector V_1 extends from origin O. The tail of V_2 is attached to the head of V_1. The resultant $(V_1 + V_2)$ extends from O and meets the head of V_2. Vector addition is shown on rectangular coordinate axes in figure 12. Vector subtraction is performed by reversing the direction of the vector to be subtracted and then performing vector addition. Figure 13 illustrates this process.

(1) Addition of vectors.



(2) Vector addition along coordinate axes.

Figure 12. Vector addition along coordinate axes.

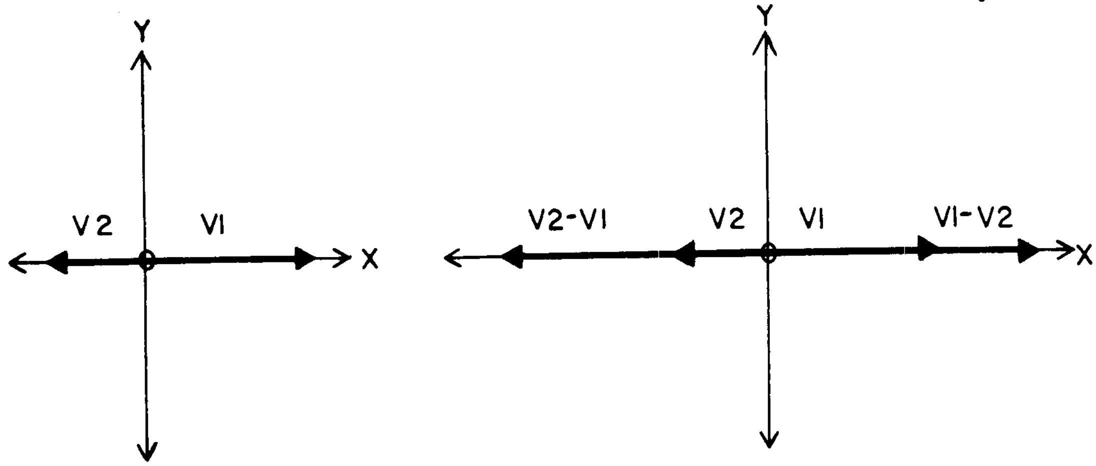


Figure 13. Vector subtraction.

Section VII. RESOLUTION OF VECTORS

18. GENERAL

The computer in a number of instances knows the components of velocity along one set of axes and needs to know the components of velocity along another set of axes. This operation of the computer, to find the components of velocity along the new axes, is called resolution of vectors. The method of converting components of velocity from one rectangular coordinate system to one which is rotated away from the original by some angle consists of drawing the axes of the new coordinate system and using trigonometry to find the magnitude of the components in the new system.

19. CONVERSION OF MISSILE VELOCITY FROM RECTANGULAR EARTH COORDINATES TO GYRO COORDINATES

As an example of the graphical conversion of components from one system to another, consider the conversion of missile velocity components from rectangular earth coordinates to gyro coordinates. Figure 14 illustrates this method. The component of $\dot{X}_M$ along the Y_G axis is $\dot{X}_M \sin A_G$; the component of $\dot{Y}_M$ along the Y_G axis is $\dot{Y}_M \cos A_G$. To find $\dot{Y}_{GM}$, these components of velocity are added vectorially, so that the vector equation for $\dot{Y}_{GM}$ is:

$$\overrightarrow{\dot{Y}_{GM}} = \overrightarrow{\dot{X}_M} \sin A_G + \overrightarrow{\dot{Y}_M} \cos A_G. \qquad (1)$$

This equation also represents the algebraic computation performed by the computer. The component of $\dot{X}_M$ along the X_G axis is $\dot{X}_M \cos A_G$; the component of $\dot{Y}_M$ along the X_G axis is $\dot{Y}_M \sin A_G$. To find $\dot{X}_{GM}$, these components of velocity are added vectorially, so that the vector equation for $\dot{X}_{GM}$ is:

$$\overrightarrow{\dot{X}_{GM}} = \overrightarrow{\dot{X}_M} \cos A_G + \overrightarrow{\dot{Y}_M} \sin A_G \qquad (2)$$

and the algebraic equation is:

$$\dot{X}_{GM} = \dot{X}_M \cos A_G - \dot{Y}_M \sin A_G . \qquad (3)$$

The missile velocity is in the direction of the resultant vector as shown in figure 15. The components of velocity along the earth axes are $\dot{Y}_M$ and $\dot{X}_M$. With respect to the gyro axes, the resultant velocity also has components $\dot{Y}_{GM}$ along Y_G and $\dot{X}_{GM}$ along X_G.

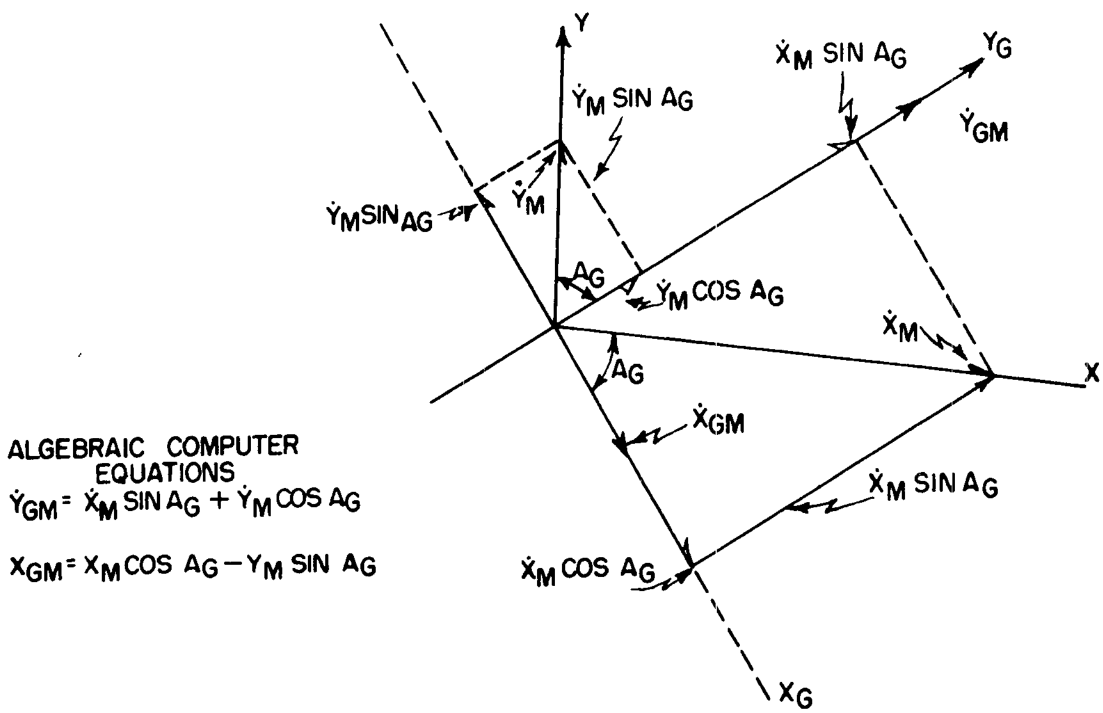


Figure 14. Conversion of missile velocity from rectangular earth coordinates to gyro coordinates.

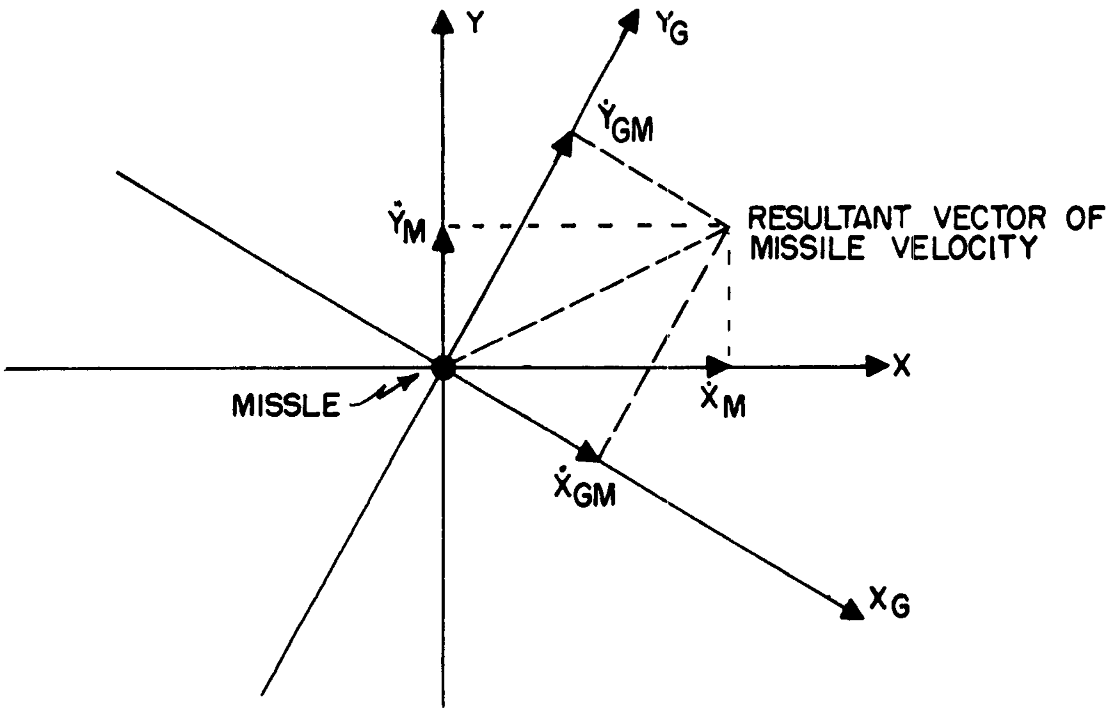


Figure 15. Components of missile velocity.

Section VIII. REFERENCE PLANES AND AXES (TM 9-5000-26)

20. GENERAL

The roll-amount gyro of the missile causes the missile to be oriented in space so that the belly of the missile points toward the ground projection of the intercept point. At this time, the rectangular earth components of actual and ideal closing velocities have been determined, and the next step in the solution of the SAM problem consists of determining the amount by which the rectangular earth components of actual closing velocity differ from the rectangular earth components of ideal closing velocity. This process is the determination of velocity errors. Velocity errors are then converted from rectangular earth coordinates to the reference planes and axes of the missile. Finally, the velocity errors are used to compute commands which are sent to the missile to change its velocity (accelerate it laterally and vertically) until the velocity error is eliminated. The reference planes are the horizontal plane, the gyro reference plane, and the missile-velocity slant plane. Each plane contains one or more reference axes. These reference axes are

shown on page 18. The three reference planes all intersect at a common point. This common point represents the instantaneous position of the missile in space. The horizontal plane is always parallel to the plane of the earth. The gyro reference plane is a vertical plane, so named because it is the plane of the reference (roll-amount) gyro in the missile. The gyro reference plane is perpendicular to the horizontal plane and is oriented in the direction of the gyro azimuth (A_G) before launch. The missile-velocity slant plane is so named because it contains the vector representing missile velocity. The missile-velocity slant plane intersects and is perpendicular to the gyro reference plane. The common line of intersection is designated as L_i. Since the direction of missile travel changes continuously, the slant of the missile-velocity slant plane also changes continuously.

21. HORIZONTAL PLANE

The horizontal plane is always parallel to the plane of the earth. The plane of the earth contains the target-tracking radar, which is the origin of all coordinate systems used for determining distances. The earth plane, the 2-dimensional rectangular earth coordinate system, is formed by the north-south (Y) and east-west (X) axes. The altitude (H) axis is perpendicular to the earth plane and to the horizontal plane. The horizontal plane contains the gyro reference axis (Y_G) and gyro spin axis (X_G). These gyro axes are mutually perpendicular and form the rectangular coordinate system used in converting rectangular earth components of velocity to components along the gyro axes. The gyro reference axis, Y_G, is the intersection of the horizontal plane and the gyro reference plane. The gyro spin axis, X_G, is the intersection of the horizontal plane and the missile-velocity slant plane.

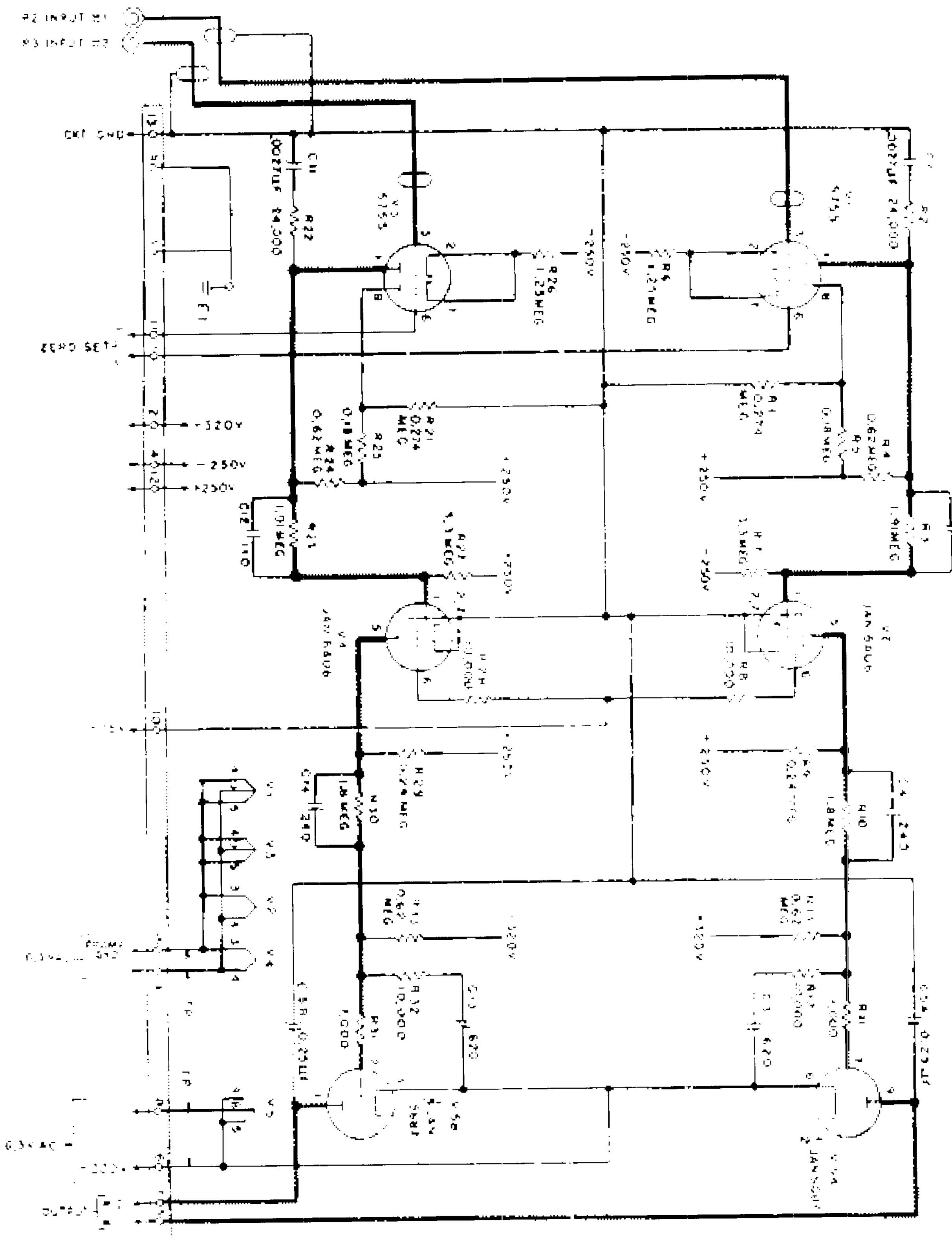
22. GYRO REFERENCE PLANE

The gyro reference plane is considered perpendicular to the horizontal plane and, therefore, perpendicular to the plane of the earth. The gyro reference plane contains the wheel of the roll-amount gyro and the predicted intercept point. The axis Y_G lies in the gyro reference plane and in the horizontal plane. Line L_i lies along the intersection of the gyro reference plane and the missile velocity slant plane. Both planes are mutually perpendicular. The climb angle (CA) is measured in the gyro reference plane and is the included angle between Y_G and L_i. Another way to define the climb angle is to state that it is the angle that the missile velocity slant plane makes with the horizontal plane.

23. MISSILE VELOCITY SLANT PLANE

This plane contains the vector which represents missile velocity and denotes the direction in which the missile is flying. The missile velocity slant plane

Figure 2. D-153846: DC Amplifier



is perpendicular to the gyro reference plane and at an angle CA from the horizontal plane. The turn angle is in the missile velocity slant plane and is measured from L_i to the missile velocity vector.

24. MISSILE AXES

Figure 16 shows the missile control fins as seen from the rear. The climb axis of the missile is perpendicular to the longitudinal axis and passes through the belly of the missile. The turn axis of the missile is perpendicular to the climb axis. The nomenclature is unfortunate, since the missile climbs by rotation around the turn axis, and turns by rotation around the climb axis. When the missile is flying level and the climb angle (CA) is zero, the climb axis and gyro axis (H_G) are coincident; therefore, the climb axis lies in the gyro reference plane. When the turn angle (TA) is zero, the turn axis and the gyro spin axis (X_G) are coincident. The turn axis always lies in the missile velocity slant plane.

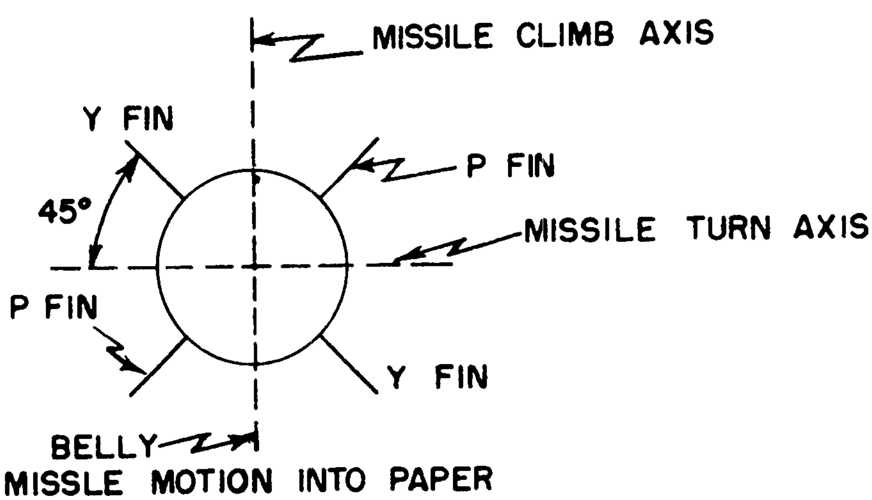


Figure 16. Climb and turn axes of the missile.

CHAPTER 3

DC AMPLIFIER CIRCUITRY

25. GENERAL

The DC amplifiers used in the Nike I computer perform a number of mathematical operations. These operations are: summing, weighting, multiplying, dividing, differentiating, data smoothing, and data holding. The performance of these operations is explained in detail in this chapter. The delivered output voltage from the DC amplifier is a function of the input voltage, but is always of opposite polarity. The input and feedback network used with each DC amplifier determines the mathematical function of that amplifier. In addition to performing mathematical operations, the DC amplifier is used in the computer to reverse the polarity of a voltage analog, and to isolate one stage from another. The DC amplifier is shown on page 22 of TM 9-5000-26.

26. GENERAL REQUIREMENTS

Since the DC amplifier is required to pass steady or slowly varying signals, the coupling between stages must be made direct. Low input and output impedances are required. High gain is required, making it necessary to compensate for internal disturbances such as noise and voltage fluctuations. Negative feedback is required to insure high stability and essentially constant amplification. When the input grid of the first stage of the DC amplifier is at ground potential, the output must also be at ground potential.

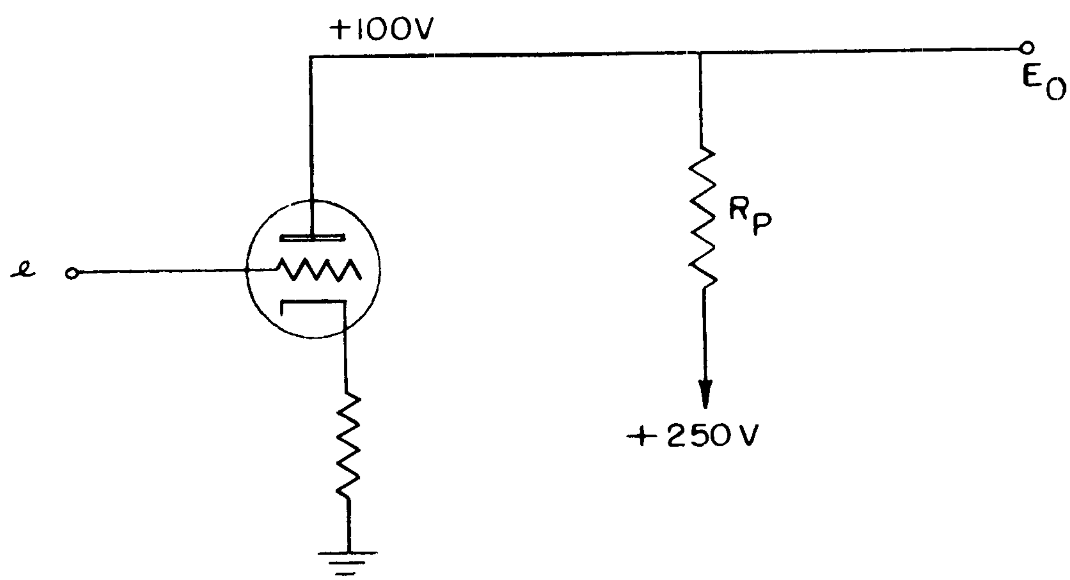


Figure 17. Single-stage DC amplifier, simplified schematic.

27. SINGLE-STAGE DC AMPLIFIER

Figure 17 illustrates a simple single-stage DC amplifier. Assume that the tube is conducting so that the plate voltage is 100 volts with no input signal, and that the gain of the tube is 10. Also assume that the stage is operating linearly. If the input were +1 volt, the tube would conduct more heavily and the plate potential would drop to 90 volts. If the input were -1 volt, the plate voltage would rise to 110 volts. By controlling the voltage on the grid, the plate current and the plate voltage may be controlled also. This simple circuit would satisfy the requirements of a DC amplifier, except for the required high gain and stability.

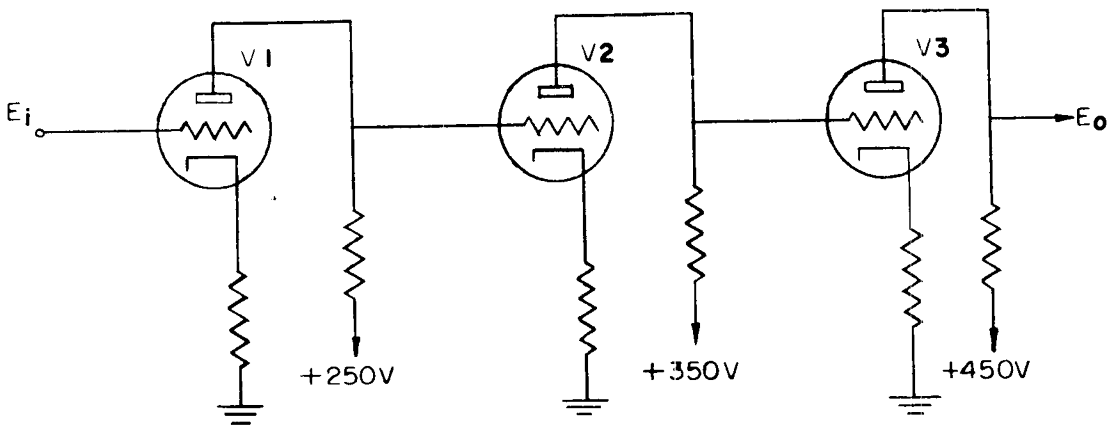


Figure 18. A basic 3-stage DC amplifier.

28. THREE-STAGE DC AMPLIFIER

A DC amplifier of greater gain is shown in figure 18. However, this circuit has the serious disadvantage of producing an output voltage of excessive magnitude when the input grid is at ground potential. If, under no-signal conditions, the voltage at the plate of the first tube is 100 volts, the grid of the second tube must also be at a 100-volt level. To obtain the correct operating point for V2, the cathode of V2 must be made approximately 100 volts positive with respect to ground. To achieve a plate-to-cathode voltage of V1, the supply voltage of V2 must be raised to approximately 350 volts. This same principle applies to the third stage, which requires a plate-supply voltage of approximately 450 volts. The output taken at the plate of V3 under no-signal condition would be around +300 volts. However, it is required that the output of the DC amplifier be zero when no input voltage is applied. This requirement may be met by the use of voltage dividers, as illustrated in figure 19, and by returning the cathode of V3 to a negative potential. By connecting a voltage divider between the plate of V1 and a negative supply, the grid potential

of V2 may be held at a value near ground that will afford the desired bias for that stage. To provide a zero potential at the plate of V3 in the absence of an input signal, the cathode of V3 must be at a potential below ground. This is obtained by returning the cathode resistor of V3 to a negative voltage source. The values of resistance in the voltage divider supplying the grid of V3 must be such that the grid potential is placed well below ground. A modified DC amplifier of this type may be refined by circuit additions designed to improve stability and accuracy and to minimize drift. Improved DC amplifiers of this type are used in the Nike I computer.

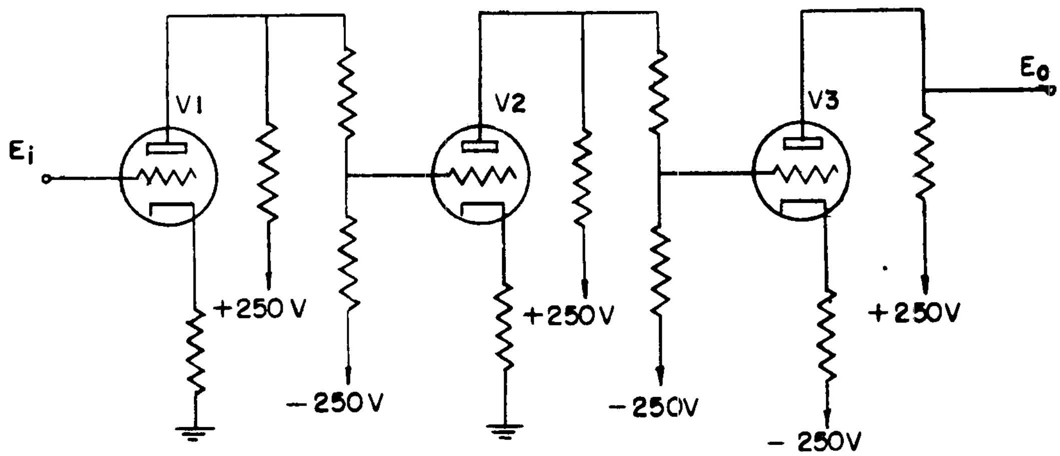


Figure 19. A modified 3-stage DC amplifier.

29. REVERSAL OF POLARITY

The output voltage of a vacuum-tube circuit is normally of opposite polarity to the input signal, except for cathode-follower circuits. Any odd number of vacuum-tube stages connected in cascade will reverse the polarity.

30. INVERSE FEEDBACK

A simple method for obtaining inverse, or negative, feedback is shown in figure 20. The amplifier is represented by a box device with a gain of K. A voltage, E_i, at the input will produce a voltage, e, at the grid. Voltage e is then amplified and appears at the output as E_o which is equal to $-K_e$. A portion of this voltage is fed back to the grid through resistor R_b. Since the feedback voltage is opposite in polarity to the input voltage, it will act to reduce the grid voltage, e. This reduction of e reduces $-K_e$, which again allows grid voltage e to increase until a point of stabilization is reached. The stabilization occurs almost instantaneously. A change in the load will cause E_o to change slightly, but inverse feedback will rapidly return E_o to its proper value. Although the use of feedback reduces amplifier gain, the

advantages of stability, accurate reproduction, and low input and output impedance which it provides are required for DC amplifiers used in the Nike I computer. Later sections in this chapter include a more complete discussion on negative feedback, input networks, and DC amplifier functions.

31. ISOLATION

Some of the computer circuits tend to very in performance as the load changes, and hence must be isolated from the load. The low output impedance characteristic of a DC amplifier makes it ideal as a buffer unit. In figure 21, the voltage drop across the two resistors must equal the 100-volt supply. If R1 and R2 are equal in value, the voltage drop across each resistor is 50 volts. If R1 is reduced to 50 ohms, so that R2 is two-thirds of the load, then the drop across R2 will be two-thirds of the supply voltage, or 66.7 volts. By changing R1 to 1 ohm and R2 to 49 ohms, the voltage drop across R2 becomes 98 volts. As R2 is increased in value from 49 ohms to 99 ohms, the drop across R2 increases from 98 volts to 99 volts, a change of only 1 volt. If R1 is made small enough, a change in R2 will have practically no effect upon the voltage across R2. Consider R1 as being the output impedance of the DC amplifier, and R2 as being the load. The effective output impedance of the DC amplifiers used in the Nike I computer is approximately 1 ohm. Because of this low impedance, the output voltage of the DC amplifier does not change as a result of normal load changes. Thus, when the DC amplifier is used as a buffer unit, a change in the load circuit will not appreciably affect the source circuit.

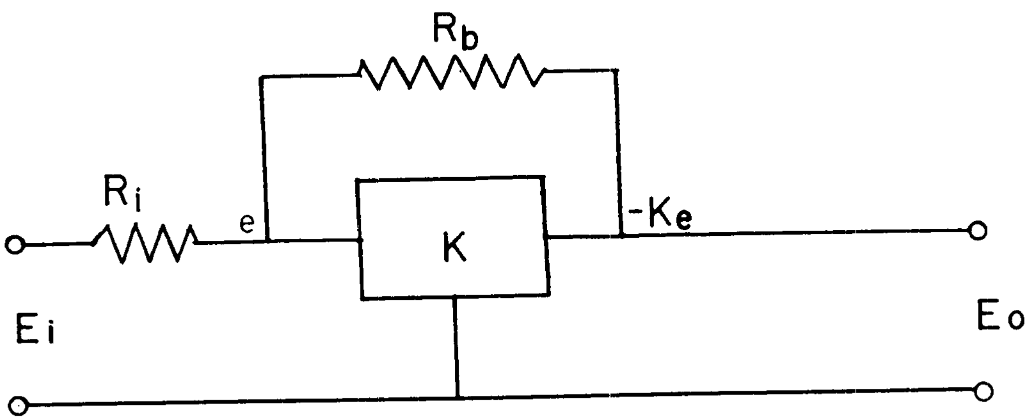


Figure 20. Inverse feedback.

32. INPUT IMPEDANCE

For an amplifier to perform algebraic operations involving several input signals, the apparent input impedance must be low. In an ordinary amplifier this impedance is extremely high. Because of inverse feedback, the effective

input impedance of the Nike I DC amplifiers is low, on the order of 25 ohms. In figure 20, the voltage drop across R_i is E_i minus e. Assume that the amplifier and the feedback circuit are replaced by a resistor connected to ground, and that the value of the replacement resistor is such that E_i and e remain unchanged. Because e is very small compared to E_i, the replacement resistor must be very small compared with R_i. But the replacement resistor is the input impedance of the DC amplifier. Therefore, the apparent input impedance of the amplifier is low.

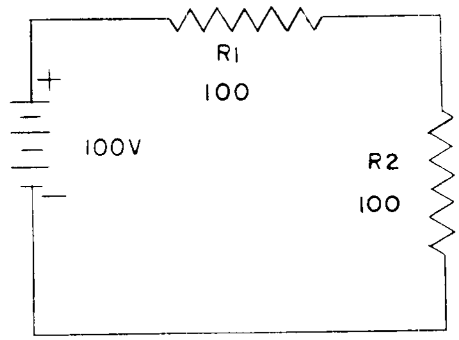


Figure 21. D-C resistance circuit.

33. DRIFT COMPENSATION

The DC amplifier must deliver an output voltage proportional to the input voltage. However, supply voltages vary and cathode emission changes. Stability and freedom from drift are extremely important in the first stage since an error here is multiplied by the gain of the succeeding stages. For example, if the gain of the second and third stages were 200 and 5 respectively, then changes in the first stage would be amplified 1,000 times in the output. Power-supply drift is corrected by careful regulation. The principal remaining source of drift is variation in operation of the vacuum tube stages, particularly changes in cathode emission. A simple method of compensation for changes in cathode emission is illustrated in figure 22. This method uses a cathode stabilizing circuit, V1B. An increase in the cathode emission of V1A would increase the plate current of V1A and would tend to increase the cathode potential. Such a change would result in increased bias for V1B, decreasing current through V1B, and thus would restore the cathode potential of the two stages to the original value. In the Nike I computer, stabilization of the first stage of the DC amplifier is accomplished with greater accuracy than the above illustration would provide. Three important drift correcting factors used are:

a. The tube used for the first stage of the DC amplifier was designed primarily for this use. It was especially designed to provide medium gain, high electrical stability, and low drift.

b. A large, unbypassed cathode resistor is used in the first stage, partially correcting for cathode variations by cathode degeneration. Since the grid of the first stage must operate near ground potential,in order to use a large cathode resistor, it is necessary to use -250 volts for the cathode voltage supply.

c. A third method of drift correction is the use of an automatic zero-setting circuit. This circuit periodically samples the potential at the input grid of the DC amplifier. If the amplifier has drifted, a small voltage will have developed at the input grid through the feedback resistor. The automatic zero-setting control amplifies this small voltage and applies it, to correct the drift, to the cathode of the first stage of the DC amplifier, through a regulator stage that uses a cathode resistor in common with the DC amplifier first stage. A complete discussion on automatic zero-setting controls is given in chapter 4.

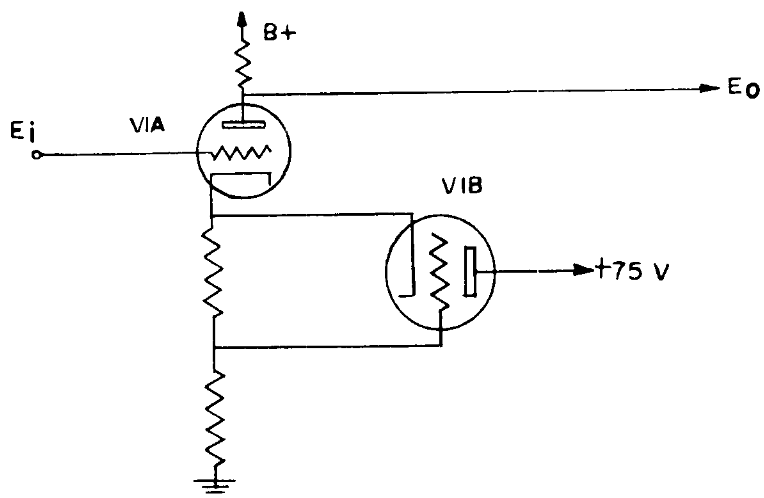


Figure 22. Cathode stabilization circuit.

34. BLOCK DIAGRAM DISCUSSION

The DC amplifier consists of three stages connected in cascade. A negative feedback circuit is connected from the plate of the output stage to the grid of the first stage. The first stage uses the A-section of a twin triode. The B-section of the twin triode is used as the regulator tube that applies the drift-correcting voltage from the automatic zero-setting control. The second stage is a high-gain pentode, and the third stage is one section of a twin triode that is capable of current amplification. Connections between stages are metallic, to accommodate passage of d-c voltages. The DC amplifiers are built on removable chassis. Each chassis mounts two DC amplifiers. The chassis are mounted in 4 rows on each of the 2 front

equipment frames inside the amplifier cabinet. The input and feedback networks for the DC amplifiers are mounted on the two front equipment frames and except for the input networks used with differentiating amplifiers, are directly below the chassis of the DC amplifier with which they are associated. The plate-load resistors for the last stages of the DC amplifiers are mounted on a special panel at the bottom of the two front equipment frames. The DC amplifier chassis are identical and interchangeable. The net gain of the DC amplifier is rated between 30,000 and 40,000. The gain is greatly increased by the use of automatic zero-setting controls.

35. DETAILED CIRCUITRY

The schematic on page 22 of TM 9-5000-26 represents one of 38 identical DC amplifier chassis used in the Nike I computer. This unit has 2 identical channels designed to operate as 2 independent DC amplifiers. To make the unit universal in application, the input circuit for each channel is mounted separately in a network that usually contains one or more input resistors and a feedback circuit. The input networks are connected to the DC amplifiers at P2 and P3. The connecting leads between the input networks and the input grid of each DC amplifier are shielded to prevent the small d-c error signals traveling over these leads from being affected by stray magnetic fields. The feedback networks and plate-load resistors for the last stages of the two DC amplifiers connect through pins 5 and 7 of P1. The plate-load resistors are mounted separately from the DC amplifiers on the plate feed resistor panel. This separate mounting facilitates maintenance and testing. Each channel uses one twin triode (type 5755), one pentode (type 6AU5), and one section of a twin triode (type 5687), for the first, second, and third stages respectively.

36. POWER REQUIREMENTS

To establish the proper operating level for each of the three stages, the following voltage supplies are used: a plate supply of +250 volts is used for the first and second stages; a plate supply of +320 volts is used for the third stage; the cathodes of the first stage are returned to the -250-volt supply; the cathode of the second stage is returned to ground; the cathode of the third stage is returned to the -200-volt supply. To establish proper grid biasing for the second and third stages, the grid resistor of the second stage is returned to the -250-volt supply and the grid resistor of the third stage is returned to the -320-volt supply. The screen grid of the second stage, the 6AU5 pentode, is biased to +75 volts from the +75-volt supply. The filaments of the tubes of the first and second stages are heated by a 6.3-volt, a-c supply. The filament of the third stage is also heated by 6.3 volts a-c. However, since the cathode of the third stage is connected to -200 volts, and since a cathode

resistor is not used, one side of the filament is connected to the cathode to prevent an excessive d-c potential from existing between cathode and filament of the stage. This eliminates the possibility of arcing between cathode and filament.

37. PHASE SHIFT AND HIGH-FREQUENCY COMPENSATION

The DC amplifier must be capable of handling fluctuating d-c signals. The a-c components present in these signals are retarded in phase between the input and the output of the amplifier. The phase lag is caused primarily by grid-to-ground, plate-to-ground and interelectrode capacitance. At some frequency, this phase lag is enough to turn the normal negative feedback into a positive feedback. Positive feedback, in turn, causes oscillation and increases the gain of the circuit. As a result, the amplifier would be unstable. Capacitors connected across the coupling resistors between stages advance the phase of the a-c components to partially equalize the phase lag. Also, the high-frequency, a-c components are attenuated through series R-C combinations connected between plate and ground of the first stage, and between grid and cathode of the third stage. High frequencies at the plate of the third stage are also shunted to ground through a capacitor. These high-frequency attenuating capacitors lower the gain of the amplifier below unity at the potential oscillating frequency, so that in spite of the regenerative feedback at higher frequencies, oscillations are not sustained and the amplifier remains stable. Capacitors C2, C4, C12, and C14 are lead capacitors shunting their respective coupling resistors. These capacitors do not solve the phase problem entirely, but they do increase the frequency at which the normal negative feedback is shifted 180° in phase to become positive feedback. Capacitors C5A and C5B, shunting the plates of the output stages of the amplifiers to ground, are the attenuating capacitors which reduce the gain of the amplifiers to less than unity at the frequency at which a 180° phase shift occurs. The R-C combinations, C1-R2, C11-R22, C3-R12, and C13-R32 perform a similar attenuating function. The combined action of the lead-producing capacitors and the attenuating networks stabilizes the DC amplifiers. The attenuating networks reduce the gain of the amplifiers to less than unity at frequencies above 20 kc, and the lead-producing networks insure that a complete 180° phase shift will not occur for frequencies below 80 kc. Thus, a wide safety margin for stability is provided. The B-sections of tubes V1 and V3 are the regulating stages through which the automatic zero-setting control drift-correction voltages are applied to the first stages of the DC amplifiers. Under ideal operating conditions, when there is no input signal, the plate of the third stage would be at ground potential. The automatic zero-setting control correction voltage would be zero and the grid of the regulator stage would be at ground potential. However, when drift causes the plate of the output stage to vary from zero potential under no-signal condition, the

feedback current will cause a small d-c potential to develop at the grid of the first stage. The automatic zero-setting control samples this voltage, amplifies it, and applies a correcting voltage to the grid of the regulator stage, of the proper polarity to correct the drift and to bring the plate of the output stage back to ground potential.

38. FEEDBACK

The term feedback signifies that some of the output signal is returned to the input of the amplifier stage. If the returned signal has the same polarity as the input, it aids the applied signal, and this feedback is termed positive or regenerative. If the returned signal is of opposite polarity, it subtracts from the applied signal and is called negative or degenerative. Since sign reversal occurs in a computer DC amplifier, the output will be opposite from the input in polarity. The feedback is a portion of the output voltage and is consequently of opposite polarity to the input voltage. Therefore this feedback is negative or degenerative.

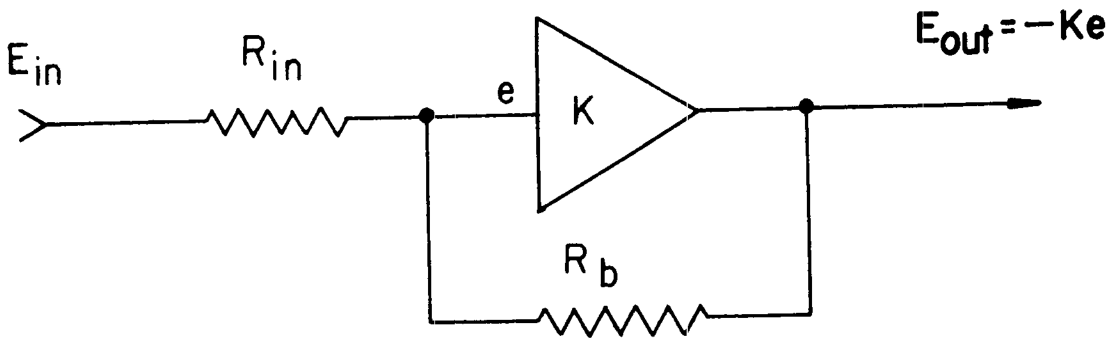


Figure 23. Simple DC amplifier with negative feedback.

39. EFFECT OF NEGATIVE FEEDBACK (fig 23)

A voltage, E_{in}, applied to the input resistor, R_{in}, produces a voltage, e, at the grid. If K is the gain of the amplifier, E_{out} will be equal to -Ke. A portion of this voltage will be returned to the input through R_b, and, since it is opposite in sign to E_{in}, it will tend to reduce e. This reduction of e in turn will reduce -Ke, since K must remain constant. Since part of the reduction will be in the feedback, e will tend to increase again. This oscillatory movement will continue until stabilization occurs. Actually, stabilization will occur almost instantaneously. Any disturbances originating within the amplifier, such as noise voltages or power supply fluctuations, will change the value of K somewhat. An increase of K will increase the value of E_{out} and, in turn, the feedback. The increase feedback will decrease e and return

E_{out} to its old value. Similarly, a decrease of K causes E_{out} and the feedback to decrease. This causes e to increase which will bring E_{out} back to the proper value. Thereby, the ratio between the input and output voltages is kept practically constant, although K may vary somewhat. Thus, the computer DC amplifier has great inherent stability because of the negative feedback used.

40. EFFECT OF INCREASED GAIN

One of the greatest advantages of negative feedback is that it causes almost perfect reproduction of the input to occur in the output if enough amplification is available. In this amplifier (fig 24), the gain is 100, and the desired output is -100 volts. The voltage at the input grid, e, obviously must be 1 volt if it is to be amplified to 100 volts by a gain of 100. The feedback will be -100 volts and will be combined with the input voltage. With this feedback, the

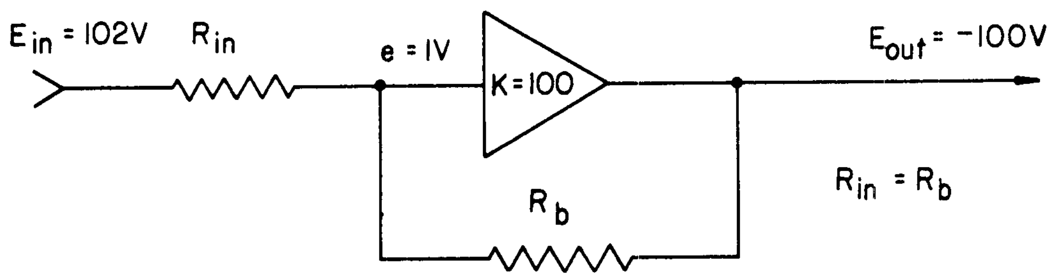


Figure 24. Simple DC amplifier with gain of 100.

input voltage must be 102 volts if e is to equal 1 volt. This may not be immediately apparent to the reader. Consider the equivalent circuit in figure 25. Resistor R_{in} is equal to R_b. In this case, the same current flows through R_b and R_{in}. Therefore, the same voltage is dropped across R_b as across R_{in}.

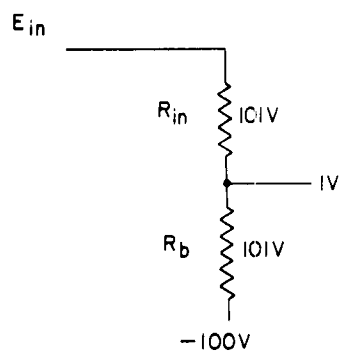


Figure 25. Equivalent circuit for figure 24.

The difference in potential between 1 volt and -100 volts is 101 volts. Therefore, the IR drop across R_b and R_{in} must be 101 volts. To have a potential difference of 101 volts between E_{in} and the input grid, E_{in} must be 101 + 1 or 102 volts. An amplifier designed to have a gain of 10,000 is shown in figure 26. Again it is desired to have E_{out} equal to -100 volts. To produce this output, e must be equal to 0.01 volt. The feedback voltage is -100 volts

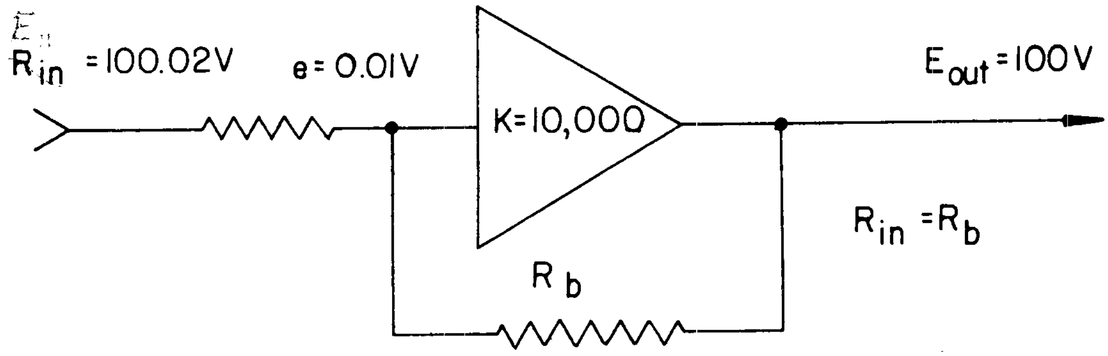


Figure 26. Simple DC amplifier with gain of 10,000.

and the voltage dropped across R_b and R_{in} is 100.01 volts. Thus E_{in} must be equal to 100.02 volts. In figure 27, the amplifier shown is similar to those found in the Nike I computer. Its gain is 20,000 and E_{out} is again -100 volts. With K equal to 20,000, e must be 0.005 volt. The IR drops across R_b and R_{in} are 100.005 volts, causing E_{in} to be equal to 100.01 volts. It is evident that the input has been almost exactly reproduced (accurate to about 10 parts in 100,000) at the output. The foregoing discussion

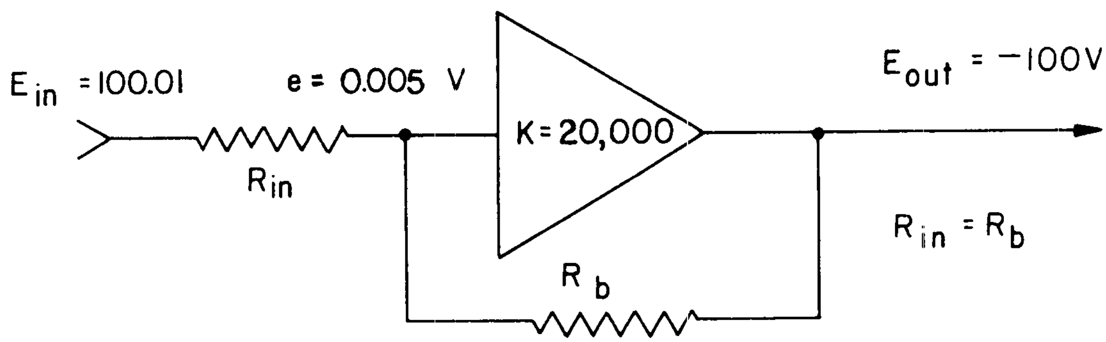


Figure 27. Simple DC amplifier with gain of 20,000.

was used to prove to the reader that the accuracy of reproduction of a DC amplifier with negative feedback is increased as the gain is increased. With the high gain of the amplifiers used in the Nike I computer, a high degree of accuracy is possible.

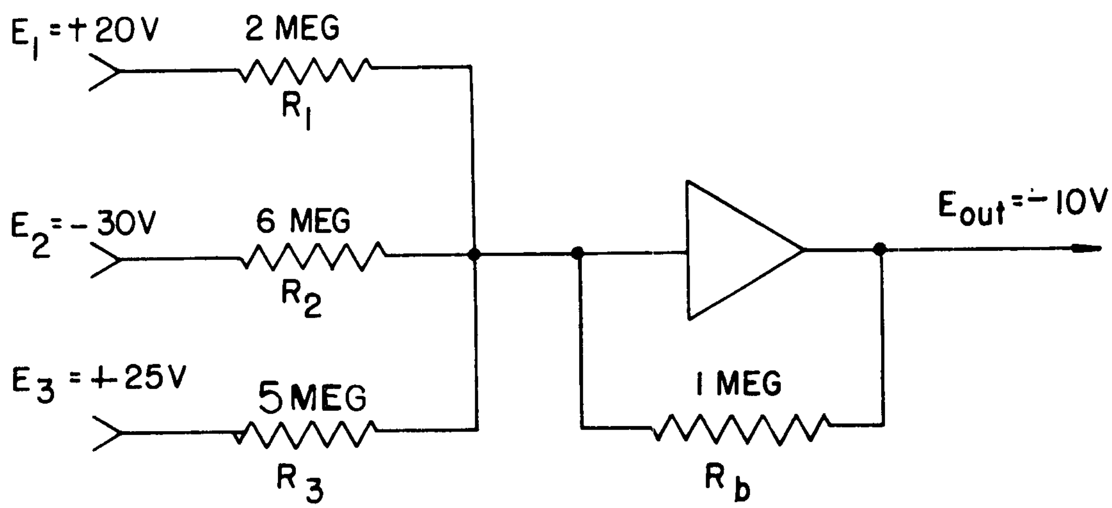


Figure 28. Summing and weighting with a DC amplifier.

41. DC AMPLIFIER SUMMING AND WEIGHTING

The DC amplifier in figure 28 has three inputs which are applied through the three resistors, R1, R2, and R3. To find the output voltage, the following formula is used:

$$-E_{out} = E1\frac{Rb}{R1} + E2\frac{Rb}{R2} + E3\frac{Rb}{R3} + \ldots E_{in}\frac{Rb}{R_{in}} \tag{4}$$

Substituting the values from figure 28 in the formula,

$$-E_{out} = (20 \times 1/2) + (-30 \times 1/6) + 25 \times 1/5),$$

or $$-E_{out} = 10 = 5 + 5 = 10 \text{ volts},$$

or $$E_{out} = -10 \text{ volts}.$$

In this problem, three voltages were added at the input to the DC amplifier. Two of the voltages were positive and the third was negative. In addition, the voltages were weighted on entry into the amplifier. The ratio between input and feedback resistors may be demonstrated by considering the input and feedback resistors as a voltage divider with the input and feedback voltages. Figure 29 shows the input and feedback resistors arranged in the form of a voltage divider. The feedback voltage may be called E_{out}, since it is a portion of the output voltage that constitutes the feedback. For this problem

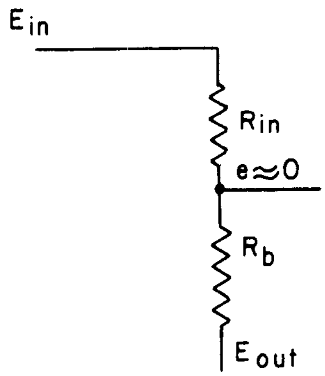


Figure 29. Ratio between input and output voltages.

consider the voltage at the amplifier input grid (the junction of R_{in} and R_b) as zero. If a voltage E_{in}, is applied to R_{in}, and R_{in} has some finite resistance, the problem is to determine how much negative voltage applied to R_b will cause zero voltage at the junction of R_{in} and R_b. Since the input grid draws almost no current, a single current flows through R_b and R_{in}. The voltage drops across R_{in} and R_b will depend upon their resistance values. A simple proportion is thus evident:

$$\frac{-E_{out}}{E_{in}} = \frac{R_b}{R_{in}} \tag{5}$$

Solving for E_{out},

$$+E_{out} = -E_{in}\frac{R_b}{R_{in}} . \tag{6}$$

This formula may be applied to single inputs or to multiple inputs as demonstrated in figure 28.

42. DIVISION

Consider the circuit shown in figure 30. The expression for the output voltage of an amplifier having such a voltage divider in the feedback circuit is as follows:

$$-E_{out} = E_{in} \times \frac{R_b}{R_{in}} \times \frac{R1 + R2}{R2} . \tag{7}$$

In this situation, with the circuit elements as indicated on figure 30, E_{out} may be computed. Substituting the values in the formula above:

$$-E_{out} = 25 + \frac{2}{1} \times \frac{25 + 50}{50} ,$$

or

$$E_{out} = -25 \times 2 \times \frac{75}{50} = -75 \text{ volts.}$$

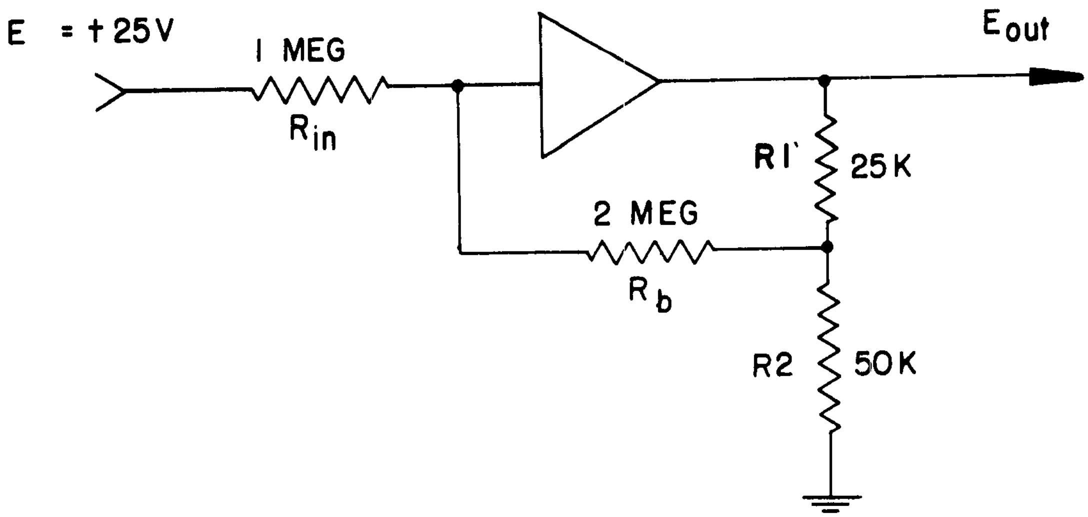


Figure 30. Division by a constant less than one.

$$+E_{out} = -20 \times \frac{1}{1} \times \frac{25}{50} = -10 \text{ volts.}$$

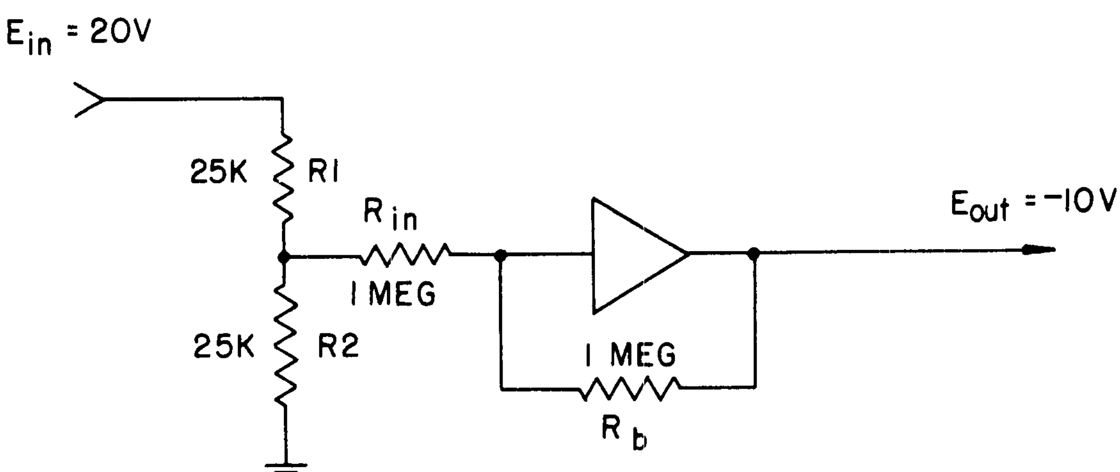


Figure 31. Multiplication by a constant less than one.

It is apparent that division has been by a constant less than 1, in this case 1/3. The student will find such voltage dividers in several feedback networks used with computer DC amplifiers. If the resistors in the feedback network are replaced by a potentiometer with the brush arm connected to the feedback resistor a similar situation results. In this case the input will be divided by a function of the brush movement, such as time or the sine or cosine of an angle.

43. MULTIPLICATION

Using the circuit shown in figure 31, an input may be multiplied by a constant less than one. In this case, the output will be represented by the following formula:

$$-E_{out} = E_{in} \times \frac{R_b}{R_{in}} \times \frac{R2}{R1 + R2} \tag{8}$$

Substituting the values shown,

$$+E_{out} = -20 \times \frac{1}{1} \times \frac{25}{50} = -10 \text{ volts.}$$

It is evident that the input has been multiplied by a constant less than one, in this case 1/2. Again, R1 and R2 may be replaced by a potentiometer which multiplies by some varying function, such as time or the sine or cosine of an angle.

44. DIFFERENTIATION

It is of the utmost important in the Nike I computer to develop voltages which represent velocities of target and missile. The student should have seen in chapter 2 that the present locations of target and missile may be determined in rectangular coordinates. The student should understand how voltages representing the coordinate rates are derived.

45. OBTAINING $\dot{X}_T$ FROM X_T

Figure 32 shows a capacitor as the input to a conventional DC amplifier. Consider an input voltage, E_{in}, having rate of change of $\dot{E}_{in}$. The voltage at the input grid of the DC amplifier is called e and is given by the following formula:

$$E_{out} = \dot{E}_{in} R_b C = -Ke, \tag{9}$$

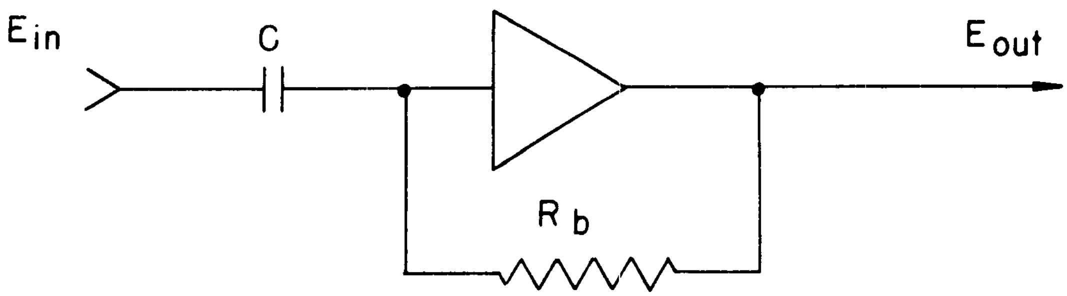


Figure 32. Differentiation in a DC amplifier.

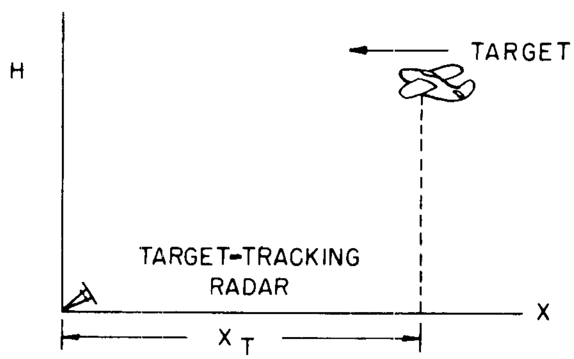


Figure 33. A target aircraft approaching from the east.

where R_b is the amplifier feedback resistor and C is the input capacitor. The terms are important in this formula: $\dot{E}_{in}$ in volts per second, R_bC in seconds, and E_{out} in volts. For a steady d-c voltage, $\dot{E}_{in}$ will be zero and it follows that E_{out} must be zero. Consider the situation given in figure 33. A target is approaching a Nike battery from the east at a certain velocity. It is possible to determine X_T from data available at the target tracking radar. If the target has velocity it must be changing at a certain rate. The problem is to develop a voltage which represents that rate. In the computer, X_T, a positive quantity, may be represented by a negative voltage. This negative voltage is going positive toward zero. It is applied to a differentiating network similar to that shown in figure 32. In the formula, $E_{out} = R_bC\ \dot{E}_{in}$, $\dot{E}_{in}$ will be positive for the conditions imposed by figure 33. Therefore, E_{out} will be a negative voltage. This is proper because the target is flying in a westerly (negative) direction. If the target were flying in the opposite direction, $\dot{E}_{in}$ would be negative and E_{out} would be positive. Again this is proper because the target would be flying in an easterly (positive) direction.

46. DATA SMOOTHING

Incorporated with the computer differentiating circuits are data-smoothing networks. The voltages which represent velocities as developed by differentiating circuits contain a considerable number of transients which must be minimized to obtain the desired system accuracy. These transients, described as electrical noise, result from random effects such as tracking antenna hunting and granularity of the wirewound potentiometer cards. The data-smoothing networks are resistance-capacitance networks which delay the transmission of variations in the rate voltages and spread their effect over a period of time, thus smoothing out irregularities. The Nike I computer uses two types of data-smoothing networks: 2-second and 4-second. The 4-second data smoothing nets are available to the computer during the prelaunch configuration for the target differentiator only. The 2-second data smoothing nets are available to the computer during the steering configuration for both target and missile differentiators.

47. FOUR-SECOND DATA SMOOTHING

In a simple R-C filter, the capacitor may be said to store the various rises and falls of the input voltage and provide a more smoothly varying d-c voltage as an average output. The larger the capacitor used, the smoother the output. The word average indicates that the voltage was considered over a period of time. In an R-C filter, the charging time constant increases if one or the other element is increased in value. Generally speaking, the larger data-smoothing time allowed, the smoother the output voltage will be. A more complex circuit is used than the simple R-C network referred to previously. The more complex network provides maximum smoothing in a minimum time delay. The 4-second data smoothing network has a response that depends upon input data during a 4-second period. It places most importance (weighting) on data only about 1.6 seconds late. A graph of this is illustrated in figure 34 and is called the weighting function. The curve in figure 34 shows the relative importance the circuit places on data with respect to the length of time during which that data are present in the 4-second period. Although the peak of this curve occurs at -1 second, the circuit delay is measured in terms of the line which divides the curve into two halves of equal area. This line occurs at -1.6 seconds. From the curve in figure 34, it is seen that there is no response at the time that data appears, but, if these data remain for a significant period of time, the response increases to a maximum. After this time, the data are too old to be very important and the response drops until, at 4 seconds old, it is completely discarded.

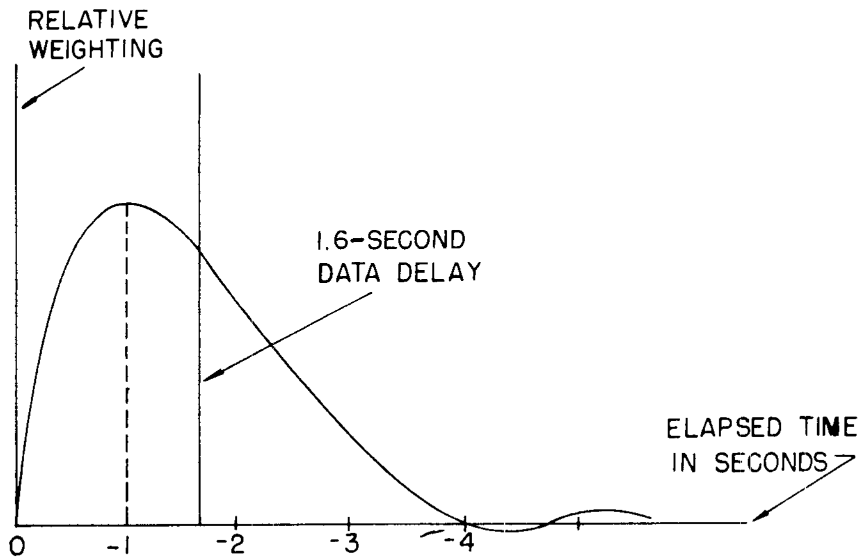


Figure 34. Weighting function for a 4-second data-smoothing network.

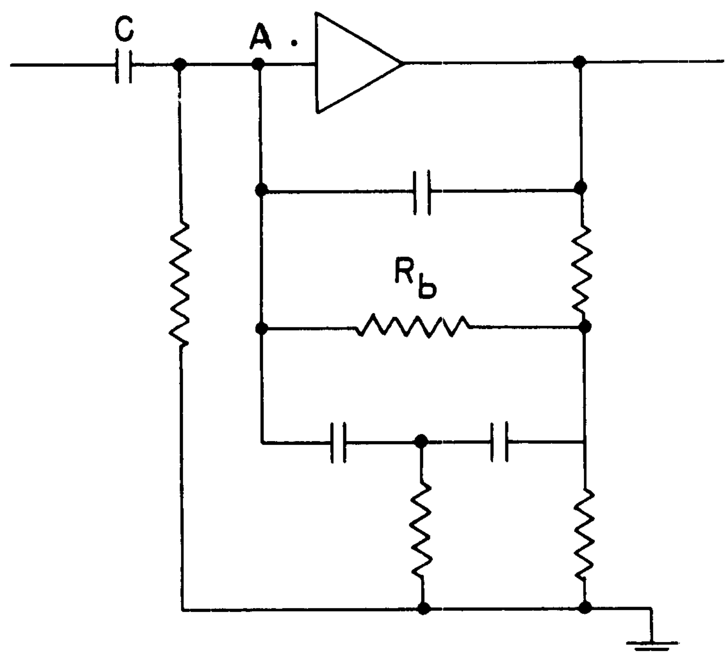


Figure 35. Differentiating amplifier, simplified schematic.

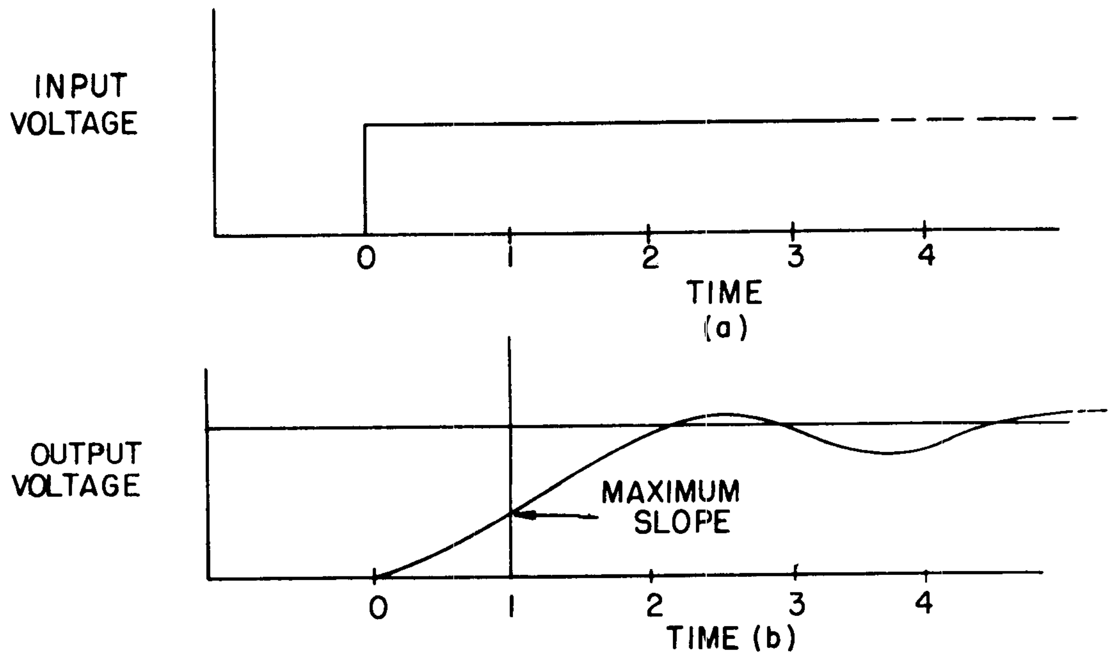


Figure 36. Input and output voltages of a data-smoothing network.

a. In actual practice, the data smoothing network is a complex R-C circuit, placed in the amplifier feedback path so as to parallel the feedback resistor. The amplifier output depends upon the characteristics of this integrating circuit. A simplified schematic of a differentiating amplifier with its input and feedback network is shown in figure 35. The input capacitor is labeled C and the feedback resistor is labeled R_b. Note the complex R-C network shunting R_b.

b. The behavior of the data smoothing network can be tested by suddenly applying a d-c voltage at point A (fig 35) and observing the output. This is illustrated in figure 36. The input is a step function as indicated in figure 36a. The output (fig 36b) at time zero is zero. One second later, the output is responding most rapidly (fig 34). Finally, after 4 seconds have passed, the output is no longer changing. The output will remain at full value as long as the input remains constant, since a DC amplifier is being used. Remember that the step function of voltage is not applied directly to the differentiator capacitor, but to the input grid of the DC amplifier.

48. DIRECT COUPLING

A DC amplifier is an electronic device that produces an output voltage proportional to the input voltage when the input voltage is a d-c signal. The symbol

DC means direct coupled. That is, the coupling between the plate of one tube and the grid of the next tube must not involve either a capacitor or a transformer, otherwise a change from one steady voltage condition to another steady voltage condition would not be transmitted. The term d-c indicates direct current, which is a steady state or nonalternating condition.

49. FUNCTION OF THE DC AMPLIFIER

There are 76 DC amplifiers in the Nike I computer. All are identical and interchangeable, except for their input and feedback networks. They may be used to perform any or all of the following different functions:

a. Reverse the polarity of the input voltage.

b. Isolate one circuit element from another.

c. Produce a d-c voltage proportional to the algebraic sum of two or more d-c voltages, either with or without weighting one or more of the input voltages.

d. Multiply or divide any of several input voltages by any desired fixed factor.

50. SPECIFICATIONS OF THE DC AMPLIFIER

a. Number of stages: 3.

b. Net gain: 20,000.

c. Apparent input impedance: about 25 ohms.

d. Effective output impedance: about 1 ohm.

e. Tubes used: first stage - 5755,
second stage - 6AU6,
third stage - One-half of a 5687.

f. As used in the computer, the DC amplifier is essentially a 3-stage, resistance-coupled, vacuum tube amplifier, using negative feedback.

CHAPTER 4

AUTOMATIC ZERO SETTING CONTROLS

Section I. OVER-ALL PURPOSE

51. GENERAL

The purpose of the automatic zero set unit is threefold. First, it reduces the initial offset voltage error of the DC amplifier. Second, it continuously compensates for the slow drift in the DC amplifier. Third, it improves the computing accuracy and helps to decrease the mathematical error by increasing the gain, K, of the DC amplifier.

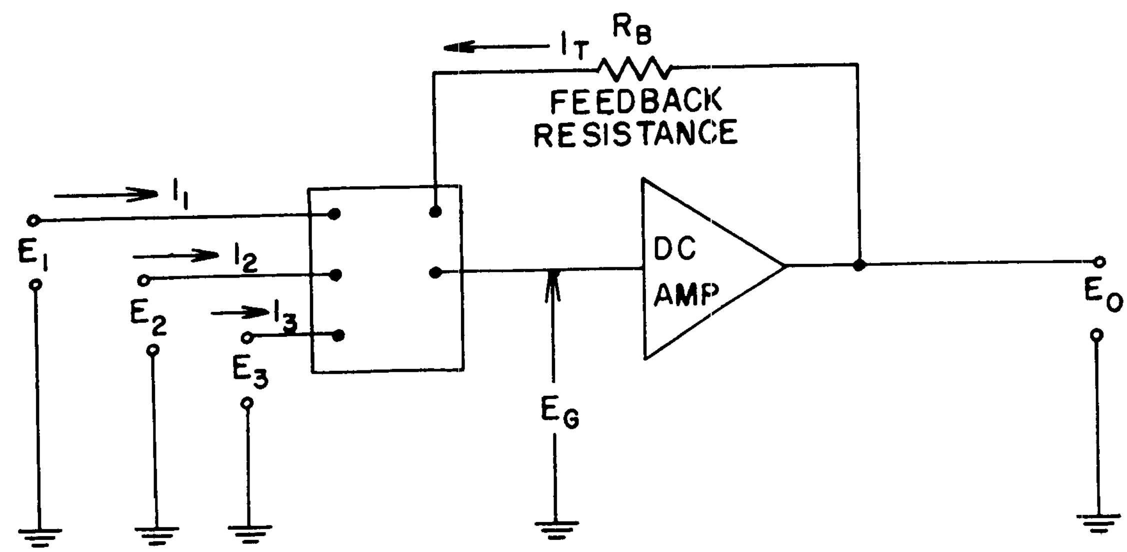


Figure 37. Summing amplifier circuit.

52. COMPUTER ERRORS

In all of the mathematical operations performed by the DC amplifier and its associated input circuit, the voltage e_g existing between the grid of the first stage and ground is made to approach zero. Figure 37 illustrates the manner in which the DC amplifier nulls the voltage for a summing circuit. The DC amplifier maintains a current flow, I_T, through feedback resistor R_B that is equal to the sum of the input currents I_1, I_2, and I_3. If I_T does not equal the sum of the input currents, an error voltage e_g will exist between the input signal grid and ground. Any deviation of e_g from zero constitutes an error in

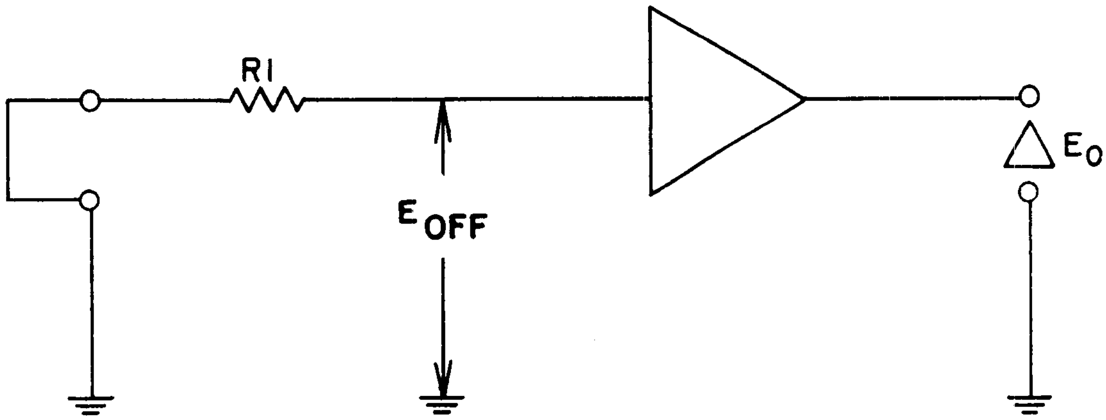


Figure 38. Illustration of offset voltage.

the computing function, because the output voltage E_0 does not represent a perfect reproduction of the input signal voltages. The zero offset voltage is, by definition, the voltage which exists at the output terminals of a DC amplifier having no feedback path when the input terminals to the network are grounded (fig 38). The zero offset voltage e_0 is expressed by the equation:

$$e_{off} = \frac{e_0}{-K} . \tag{10}$$

Where e_{off} is the offset voltage existing between the input signal grid and ground; e_0 is the zero offset voltage existing at the DC amplifier output; and $-K$ is the gain of the DC amplifier. The zero offset voltage, one of the greatest handicaps in the use of DC amplifiers, consists of two components: initial offset voltage, and drift voltage. The initial offset voltage is the voltage arising from manufacturing variations in tubes and components so that the operating conditions differ from one unit to another. Therefore, it is impractical to build the amplifiers so that they will give zero output with zero input. The drift voltage is the offset voltage caused by the slow change of the circuit parameters due to heating, aging, variations in the plate and filament voltage supply, and by changes in the vacuum tube characteristics caused by heating, vibration, shocks, and thermal effects. There is another type of error which is quite distinct and completely separate from zero offset voltage error. It is called the mathematical error. In any DC computing circuit with feedback (fig 37) this error is present because the computing circuit does not perform the exact mathematical operation. Eliminating any offset voltage error, the feedback current still does not exactly equal the signal input current. The mathematical voltage error at the input grid to ground is designated by $e = \frac{-E_0}{K}$ where E_0 is the output signal voltage, and K is the interval gain of

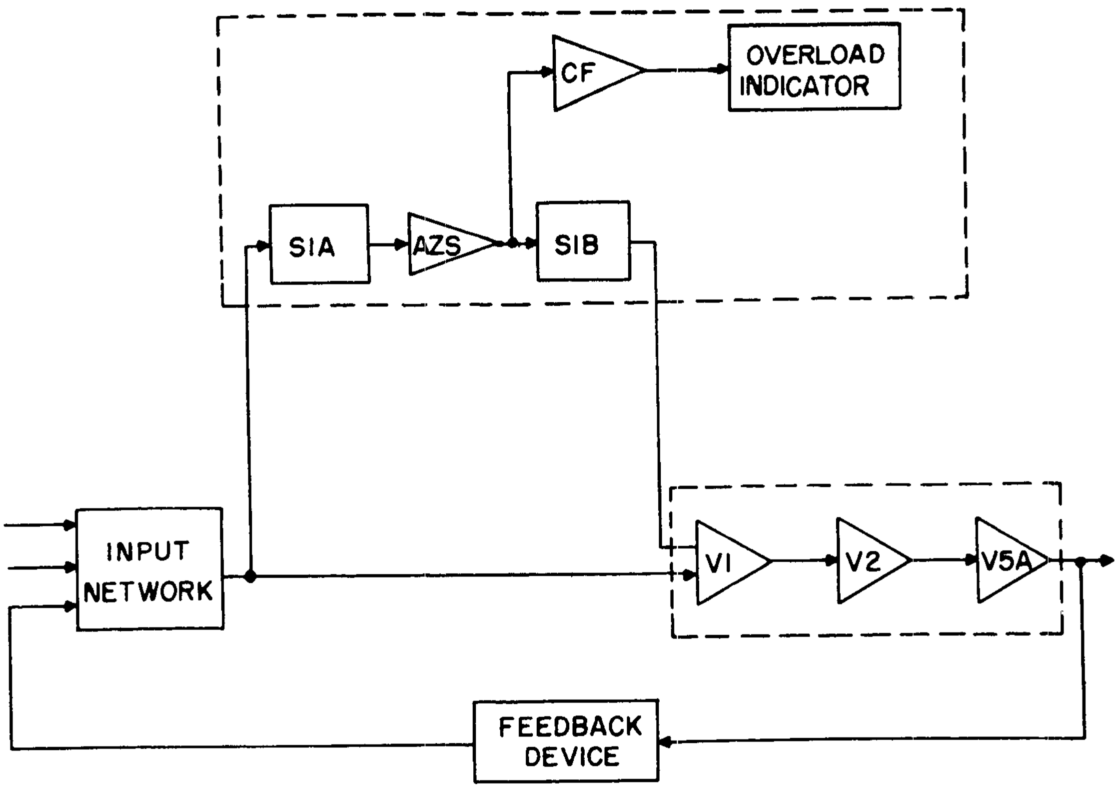


Figure 39. Automatic zero setting, typical block diagram.

the amplifier. Error voltage e_g on the signal grid consists partly of the offset voltage e_{off} and partly of the mathematical error voltage e. If e_g were reduced to zero, the output voltage E_o would be a perfect reproduction of the input voltages to the DC amplifier. By increasing the gain of the DC amplifier, the magnitude of the error voltage e_g will be decreased.

53. PRINCIPLES OF AUTOMATIC ZERO SETTING (fig 39)

The DC amplifier is a 3-stage amplifier having a balanced twin triode first stage with a common cathode resistor. The total error caused by the offset error and the mathematical error manifests itself at the summing point, the grid of V1A. The basic purpose of the automatic zero setting system is to reduce the error voltage on the grid of V1A to zero. A positive error is taken for an example. This positive error is sent through an a-c amplifier, its polarity is reversed, and it is applied as a negative voltage to the correction grid of V1B. The reduction in plate current through tube V1B causes the common cathode potential to go in a negative direction. This effect is the same as if the grid of V1A had become more positive; therefore, tube V1A draws

more current, its plate voltage drops, and this negative-going signal is sent through tubes V2 and V5A. The signal output, in this example, has become more negative, and the feedback to the grid of V1A is more negative. This larger negative feedback tends to cancel the original positive error voltage. This readjustment continues until the error voltage is zero. Any attempt to amplify this d-c voltage in the AZS amplifier would be met by the same difficulties as in the DC amplifier. Therefore, the automatic zero set (AZS) amplifier is an a-c amplifier. Since an a-c amplifier does not respond to steady d-c signals, the voltage is chopped by a rotary switch before amplification. The output of the AZS amplifier is reversed in polarity. It is demodulated by the other half of the rotary switch. This method of demodulation is known as synchronous switching. The output of the AZS amplifier is stored on capacitor C3 (fig 39) attached to the correction grid of the DC amplifier. The closer the signal input grid voltage approaches zero, the more precisely the output of the DC amplifier approaches the desired function of the input. In other words, the more precise the zero setting, the more accurate the DC amplifier. However, the precision of zero setting is dependent upon and is directly proportional to the amplification in the automatic zero set circuit. In the Nike I computer, there are two types of automatic zero setting systems. One is called the precision automatic zero set system, and is used where more stringent requirements on computing accuracy are needed. The other type is the semiprecision automatic zero set system, and it is used where less computing accuracy is required. Since the precision AZS system requires greater computing accuracy, a greater amount of amplification is needed.

54. COMPONENTS (TM 9-5000-26)

a. The DC amplifier to be zero set.

b. The zero set switch and network GS15640 (page 27) or switch and network GS15557, (page 28).

c. AZS amplifier GS15641, (page 29). This is an a-c amplifier with one stage of amplification followed by a double cathode follower for overload indicator circuits.

55. TYPICAL BLOCK DIAGRAM

One AZS switch has either 12 or 6 possible configurations for completing a zero set circuit, depending upon whether it is a semiprecision or a precision switch. The switch connects the DC amplifier and its input network and feedback device across the AZS amplifier.

Section II. SEMIPRECISION AUTOMATIC ZERO SET SYSTEM

56. GENERAL (TM 9-5000-26)

The purpose of the semiprecision AZS system is to reduce the initial offset voltage error continuously, to compensate for the slow drift in the DC amplifier, and to improve the computing accuracy and decrease the mathematical error by increasing the gain of the DC amplifier. The automatic zero set switches are located in the center of the equipment frame in the computer amplifier cabinet assembly (pages 4 and 5). ZS groups 1 and 5 are precision AZS switches, and ZS groups, 2, 3, 4, 6, 7, and 8 are semiprecision AZS switches. The AZS a-c amplifiers for each group are located directly below their respective switches. The meters at the top of the cabinet display the magnitudes of the voltages present at the outputs of the amplifiers in the computer (page 29A7 and D7). Meters M1 and M2 (page 5) are meters M19 and M319 respectively on page 29 . There are two zero check switches on the center post of the amplifier cabinet. Operating these switches removes all inputs to the amplifiers. A check can then be made of all amplifiers to see if any amplifier has a zero offset voltage or is drifting.

57. DETAILED FUNCTIONAL OPERATION (TM 9-5000-26)

The operation of the semiprecision automatic zero set system is shown on page 26C1 to C5 This example shows the AZS system used in conjunction with the $+X_M$ amplifier. A lead from the signal grid of V1A of the $+X_M$ amplifier is connected to the zero set net at A4. (Note 2 indicates specific terminals or apparatus identified in the tabulations. The $+X_M$ amplifier is in semiprecision group 2, switch channel 2 (page 26B6). (All the other amplifiers are similarly tabulated.) The error signal enters the rotary switch S1A at contact 4. The contact arm of the AZS switch is revolving and makes contact at each point at a rate of five times per second. As the rotary arm revolves, it makes contact with pin 1, which is at ground potential, pin 2, which is connected (in this group) to the $-X_M$ DC amplifier, pin 3, which is grounded, pin 4, which is connected to the $+X_M$ DC amplifier, and so on through 24 contacts. The odd-numbered contacts are all grounded to permit the AZS amplifier to return to its quiescent state between each operation. This prevents any offset error voltage of one DC amplifier from being applied to the next DC amplifier which is being zero set. The even numbered contacts receive the error signal from each of 12 different DC amplifiers in sequence as the brush arm makes contact. When the brush arm contacts pin 4 on the left side of AZS switch S1A (C2), the $+X_M$ signal grid is connected to the outer ring of the rotary switch and from the ring to the signal grid of the AZS a-c amplifier. The error signal is amplified and reversed in polarity and passes through a coupling capacitor to the outer

ring of S1B. Since the opposite roller of the brush arm is in contact with pin 4 of S1B, the correction signal is connected to the correction grid of V1B in the $+X_M$ DC amplifier. Assume that the error signal on the grid of V1A in figure 39 is positive. It is amplified and reversed in polarity in the AZS amplifier, and the negative correction signal is applied to the correction grid of V1B. This negative voltage on the grid of V1B reduces the plate current flow in the tube, thus causing the voltage on the common cathode resistor to change in a negative direction. Tube V1A draws more plate current, its plate voltage changes in a negative direction, and this negative-going signal is amplified by V2 and V5A. This signal is negative at the output of the DC amplifier; therefore, the feedback voltage to the grid of V1A is more negative. This negative feedback tends to reduce the positive error signal at the input to the DC amplifier to zero. The over-all gain of the AZS circuit depends not only upon the gain, K, of the AZS amplifier, but also upon all of the associated circuit elements (C1, C3, and R3) and the speed of rotation of the rotary switch. The over-all gain of the AZS circuit is 200 (46 db). When the AZS circuit is connected to the signal grid of the DC amplifier, the AZS circuit multiplies the gain of the DC amplifier by 200. At coordinates 26C5 of 2y are a 1-megohm resistor and a 1-microfarad capacitor. In the $+X_M$ DC amplifier circuit, these are R83 and C80B (26C6), which are used as an integrating network. When the brush of the rotary switch is not in contact with the $+X_M$ amplifier, the grid voltage of V1B is maintained at a level by R83 and C80B. Without this circuit, conduction of V1A would drop as S1B moved away from contact 4. The amplifier would be unbalanced, and an error would be generated. The purpose and use of the overload indicator will be covered later.

58. MECHANICAL OPERATION

There are 6 semiprecision zero set switches and 2 precision zero set switches to zero set 76 DC amplifier, +250-volt regulator, and the +S voltage amplifier. The +S voltage (106.667 volts) is used in the computer for an accurate slant range measurement. If this voltage is incorrect, then all of the computations and scale factors in the computer will be wrong. The +S voltage amplifier is zero set to prevent drifting. Each semiprecision zero set switch handles 12 DC amplifiers, except group 4, which handles 5. Each precision zero set switch handles six DC amplifiers (page 26A6, A7, and A8). The typical semiprecision zero set circuit on page 26C2 and C4 shows the electrical connections of switch S1 correctly, but it is misleading as to mechanical operation. Figure 40 indicates that each of the contacts is a movable pin. The odd-numbered pins are connected to ground. Each even-numbered contact pin of S1A is connected to the V1A grid of a different DC amplifier. The even-numbered contacts of S1B are connected to the V1B grid of the corresponding DC amplifier. Closely spaced behind all the pins of S1A is a semicircular

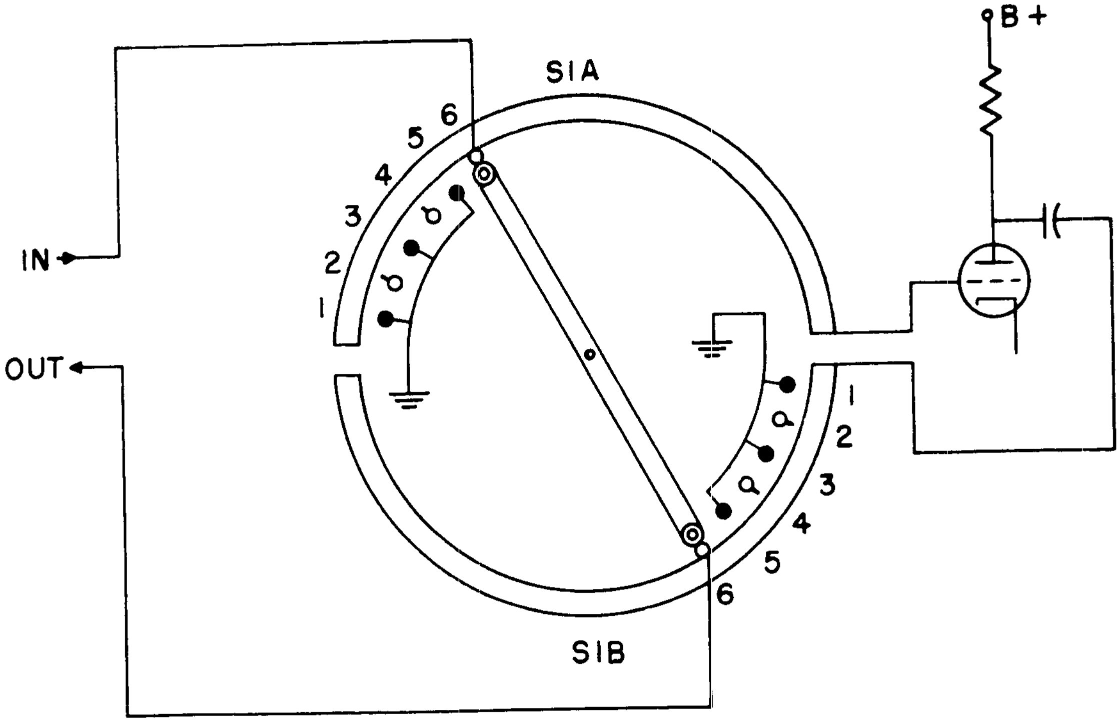


Figure 40. Mechanics of the semiprecision automatic zero set switch.

metal contact that is electrically connected to the grid of the AZS amplifier. A similar metal contact is spaced directly behind the pins of S1B. The rotary switch arms are nonconductors, pivoted in the center, with insulated rollers at each end. These rollers push the contact pins, one at a time, back against the semicircular ring to make the connection. A 2-phase induction motor rotates the arms of the switch at about 155 rpm. Effectively, the speed is 310 rpm because there are two arms on the rotary switch. Each amplifier is zero set about five times per second. Mechanical and physical limitations and space considerations dictate the speed of the brush arms. Most important, the AZS switch chops the d-c error signal into a function resembling a square wave so that the AZS a-c amplifier can amplify it. The reason for using an a-c amplifier is stated in paragraph 53.

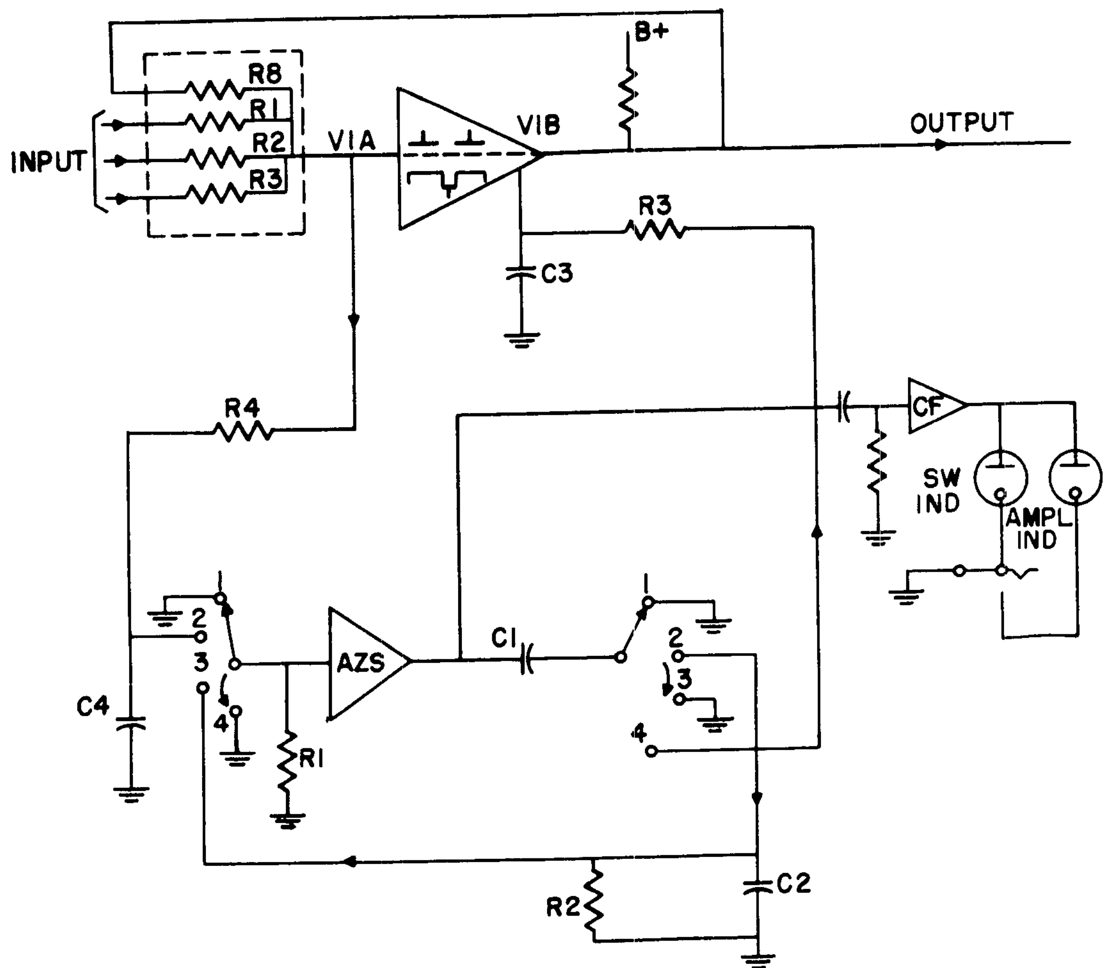


Figure 41. AZS syatem, precision reentrant type.

Section III. PRECISION ZERO SET SYSTEM

59. GENERAL (TM 9-5000-26)

The precision zero set system is used for zero setting the DC amplifiers in which more stringent requirements of computing accuracy are needed. Groups 1 and 5 (page 26C6) are precision zero set amplifiers. They are located at the top center of the equipment frames in the computer amplifier cabinets (page 29C5). The specifications for the precision automatic zero set system in the Nike I computer requires a voltage gain of 3,000 (70 db) in the AZS circuit. This gain is obtained through a circuit called the 4-step reentrant automatic

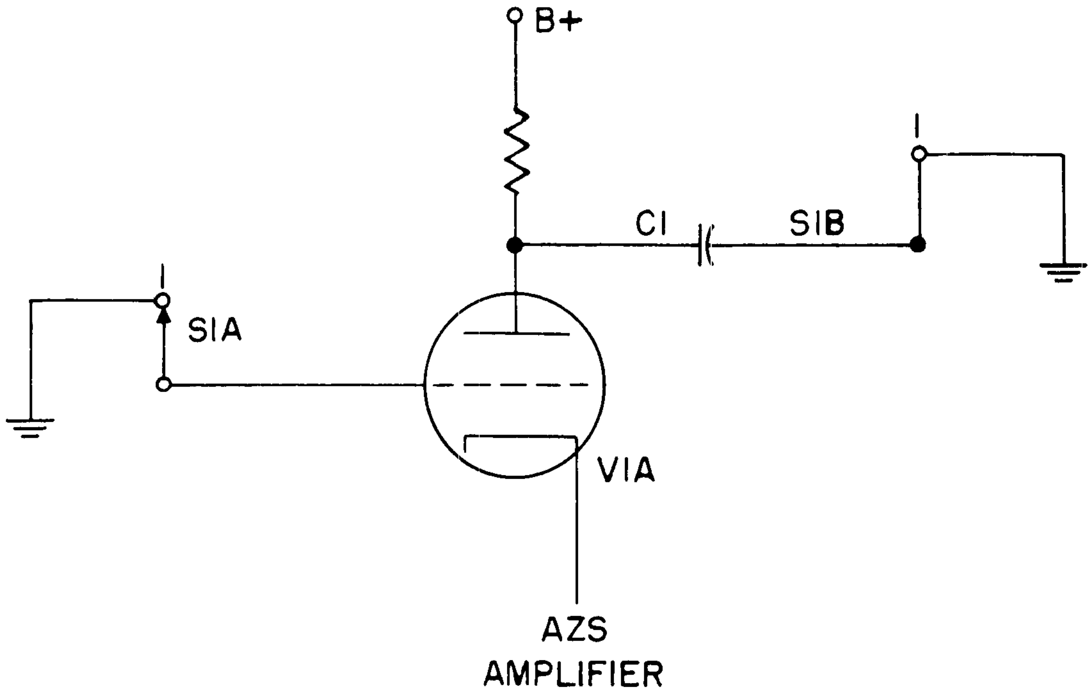


Figure 42. Step 1, precision reentrant AZS system.

zero set circuit. The same AZS amplifier and the same motor-driven rotary switch used in the semiprecision zero set systems are used. Each precision automatic zero set unit monitors only 6 DC amplifiers, since it takes 4 terminals for the 4 steps involved.

60. DETAILED FUNCTIONAL OPERATION (TM 9-5000-26)

The operation of the precision automatic zero set system is shown on page 26A1 to A5. This example shows the precision AZS system used in conjunction with the $+H_M$ amplifier. Although the DC amplifier is much more accurately zero set, the final outcome is the same; the error signal on the grid of V1A is made to approach zero. Even the method of zero setting is similar except for a few extra steps in the process. A simplified schematic of the reentrant method of automatic zero setting is illustrated in figure 41. This method requires four steps to zero set the DC amplifier. Assume that there is a positive error signal present on the grid of V1A. Capacitor C4 is charging to the magnitude of this positive voltage. In the first step of the reentrant system (fig 42), the grid of the AZS amplifier and the right plate of capacitor C1 are grounded. Capacitor C1 charges to the quiescent value of

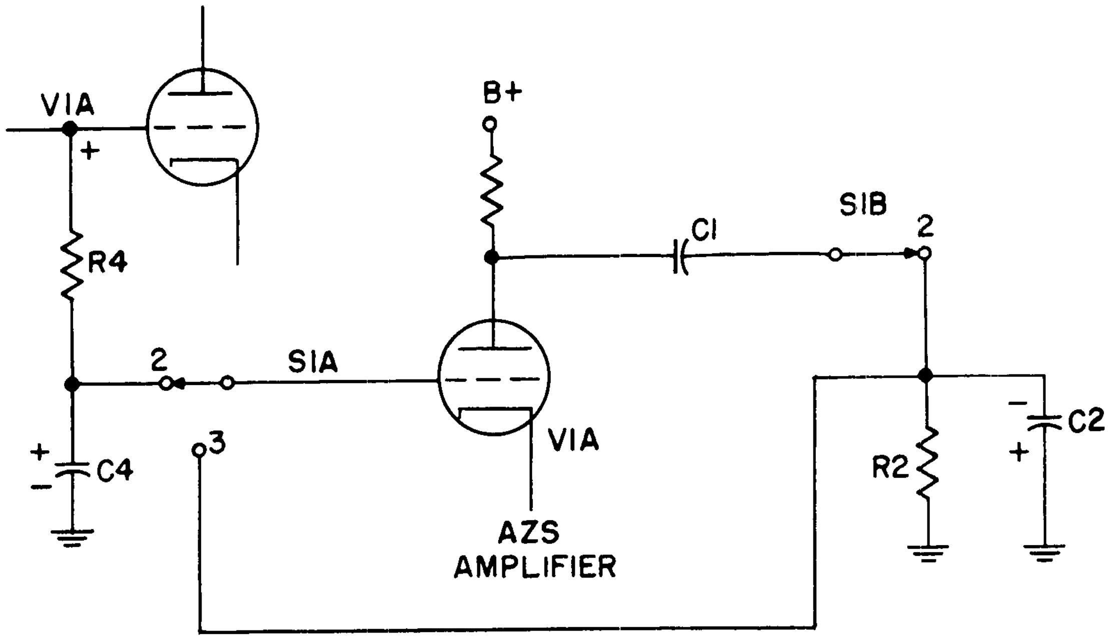


Figure 43. Step 2, precision reentrant AZS system.

the plate voltage of the AZS amplifier tube. This voltage depends on the value of the current through the tube; the charge on the cathode capacitor; and even on the prior values of the error signals on grid V1A of the DC amplifier. The important thing to remember is that C1 is now charged to a voltage which is used as a reference level. In the second step, the input to the AZS amplifier is connected to the junction of capacitor C4 and resistor R4, and the output is coupled through capacitor C1 to capacitor C2 and resistor R2 in parallel. Capacitor C4 is charged to the positive error voltage on the signal grid of V1A (fig 43) and is called the residual voltage. A positive signal on the grid of the AZS amplifier causes the plate voltage to go negative. This negative change is coupled through capacitor C1 and a fraction of it is stored on capacitor C2. Capacitor C1 remains essentially at the quiescent plate voltage. When the residual voltage is zero (no error signal on grid V1A), the voltage on C1 remains at the quiescent value of plate voltage, and the voltage on C2, having been zero, remains zero. In step three, the AZS amplifier is disconnected from the input of the DC amplifier, and the storage capacitor C2 is transferred to the input of the AZS amplifier. At the same time, C1 is grounded. The amplifier residual voltage on C2, a negative potential, is applied to the grid and amplified and reversed in polarity by the AZS amplifier. Capacitor C1 charges from the quiescent plate voltage to a voltage equal to the quiescent voltage plus the reamplified residual voltage. In the fourth step,

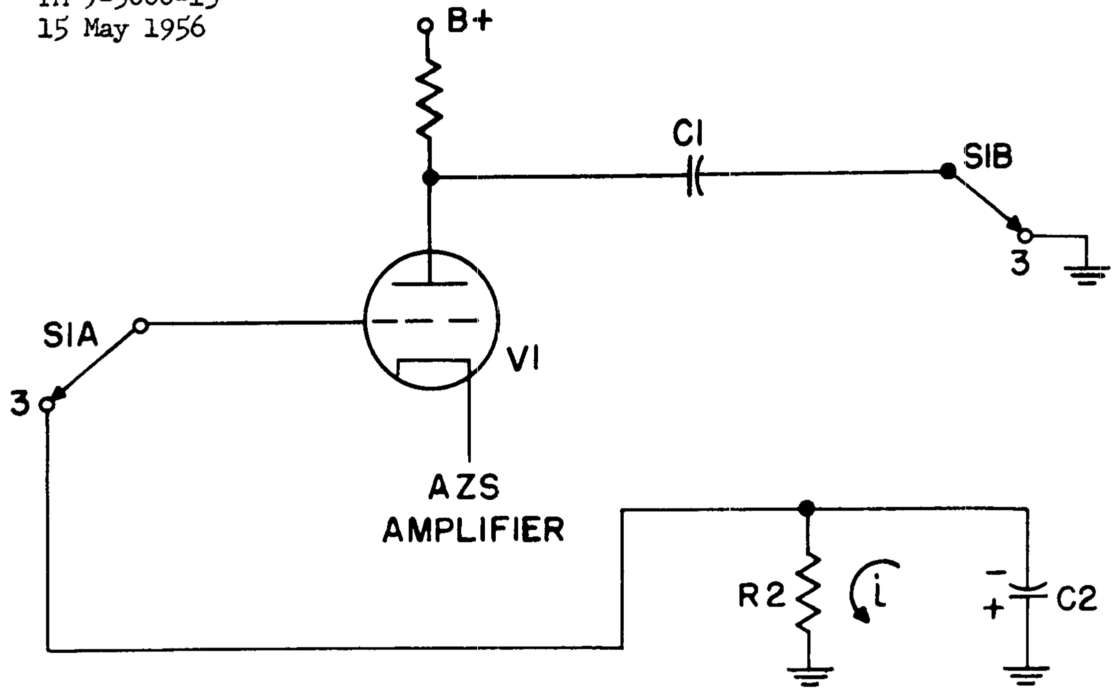


Figure 44. Step 3, precision reentrant AZS system.

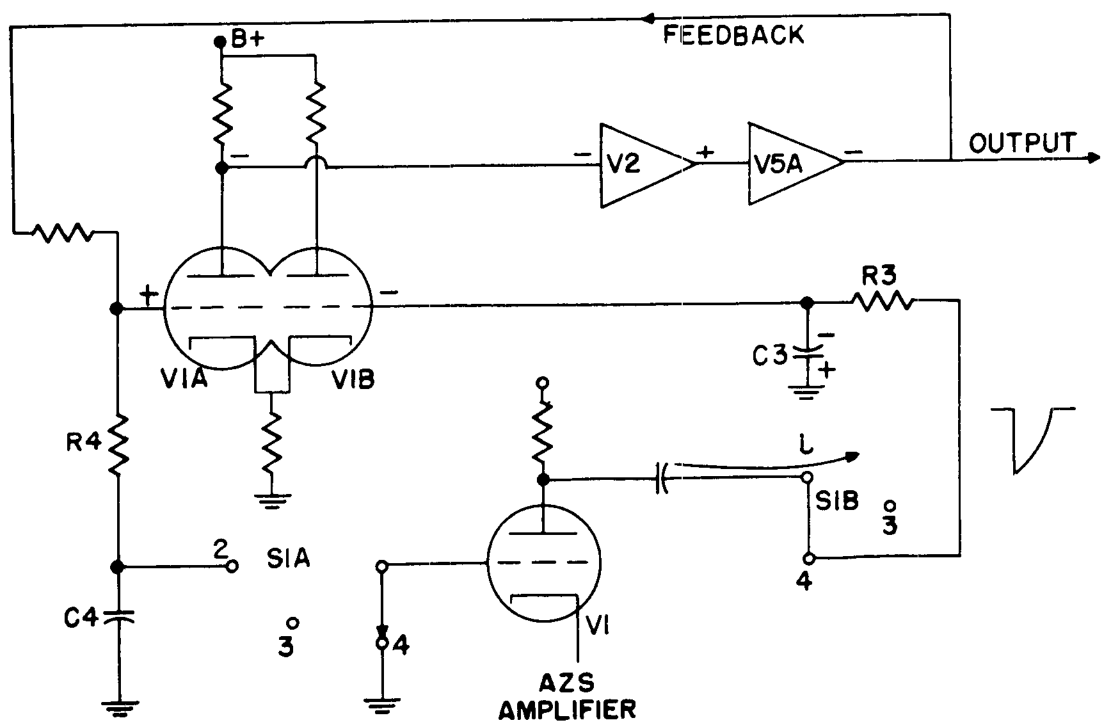


Figure 45. Step 4, precision reentrant AZS system.

the input to the AZS amplifier goes from a negative potential to ground, causing the grid to rise. At the same time, capacitor C1 is connected to the integrating circuit made up of capacitor C3 and resistor R3. The amplifier plate voltage goes negative returning to its quiescent value. The important thing is that the negative change in plate voltage is coupled through C1 and applied to the upper plate of capacitor C3. The values of C1, C3, and R3 are chosen so that C3 changes in voltage by an almost equal amount, but opposite in polarity to the error voltage on the grid of V1A. In figure 45, it can be seen that a positive error on the grid of V1A results in a negative voltage being applied to the grid of V1B. This is the correct polarity in voltage to make the positive error signal on V1A approach zero. In summary, a positive error on the signal grid, V1A, of the first stage of the DC amplifier is the result of an initial offset error, drift, or a mathematical error. Any or all of these voltages can reduce the feedback current, and cancellation of the voltage at the input grid, V1A, is not complete. Thereby, there is an error signal at the input of the DC amplifier when there should be zero voltage. If this positive error signal is sampled by the precision reentrant AZS system, a negative voltage is placed on the grid of V1B. The plate current through V1B is reduced, the common cathode becomes less positive, and plate current in V1A increases. The plate voltage of V1A drops and this negative change in voltage is amplified and reversed in V2, and amplified and reversed in V5A (fig 45). The output is a negative signal, part of which is fed back to the input grid of V1A to cancel out the positive error voltage. The precision AZS system is used with DC amplifiers that requires great accuracy to perform their functions properly. The gain of the precision system is 3,000 (70 db), which accounts for its extreme accuracy with respect to the semiprecision system whose gain is only 200. The magnitude of gain of the precision system will reduce the maximum expected voltage offset of 0.5 volts at the signal grid of the DC amplifier to approximately 0.13 millivolts.

61. MECHANICAL OPERATION

The precision AZS switch operates mechanically exactly the same as the semiprecision AZS switch does. However, the various pin connections are not the same. The GS-15557 switch used for the precision zero set system is shown in 2y, page 28. Using this rotary switch having 24 input and 24 output contacts, 6 DC amplifiers can be set by the 4-step reentrant system. In paragraph 58 a description of the mechanical operation of the AZS switch is given.

Section IV. OVERLOAD INDICATOR

62. GENERAL (TM 9-5000-26)

The use of the precision and semiprecision automatic zero set circuits requires that an indicator circuit be provided which will detect an overloaded DC amplifier. A cathode follower circuit (page 29) conducts enough on receiving an overload signal to give an indication by lighting a flashing neon lamp.

63. DETAILED FUNCTIONAL OPERATION (TM 9-5000-26)

The cathode follower circuit (page 29) consists essentially of a 2C51 tube, a twin triode, the two halves of which are operated in parallel. The cathode is biased at approximately zero potential and is capable of swinging a minimum of ±100 volts. Resistor R9 in the grid circuit of the cathode follower is large enough to prevent undue loading of the plate of the AZS amplifier tube. The 1μfd capacitor, C5, between the plate of the 6AK5 and the grid of the 2C51 is large enough to prevent appreciable alteration of its charge during the interval that a signal is applied to the AZS amplifier and, therefore, will cause no crosstalk. Resistors R7 and R8 prevent C5 from charging if the 2C51 draws grid current at any time. Resistors R11 and R12 act as a voltage divider to bias the grid at a value that keeps the voltage of the 2C51 approximately zero with no signal applied. When the cathode of the 2C51 is driven ±100 volts, the neon lamp will fire and enough current will be supplied to cause a bright flash. Two neon lamps are associated with each AZS unit for indicating a bad amplifier. One of the neon lamps is located on the computer control panel, and it indicates the AZS switch with the overloaded DC amplifier. A second neon lamp is provided in the AZS switch. If the neon lamp at the computer control panel flashes, the computer operator goes to the indicated AZS switch and presses a nonlocking key on the switch, which transfers the indication to the neon lamp in the AZS switch. Through a lucite arm that rotates with the shaft of the switch and numbered holes in the cover, the overloaded or bad amplifier on the AZS switch can be identified. A permanently lighted neon lamp indicates the failure of the cathode follower tube. There is no permanent indication for the failure of the 6AK5 tube.

amplitude of 60 volts. The two voltages are 180° out of phase. From figure 46, it is apparent that these two voltages are each 90° out of phase with phase C (mtr X).

CHAPTER 5

SERVO LOOP ELEMENTS

Section I. EXCITATION VOLTAGES

64. GENERAL

The Nike I system uses several 2-phase motors. These devices require two 400-cycle signals, 90° out of phase. Primary power furnished by the generators is 3-phase power. A particular type of transformer connection, similar to the Scott connection, develops a voltage 90° out of phase with phase C of primary power. Phase C provides exitation for all computer and plotting board motors (mtr X). The two voltages produced by this connection are each 90° out of phase with phase C and 180° out of phase with each other. These voltages, called tachometer excitation (tach X) are 60-volt, 400-cycle, phase AB or BA, (fig 46). Tach X1 or tach X2 provides excitation for all feedback generators in the computer and plotting board servos. Tach X1 and tach X2 together provide the 400-cycle input to the modulators, with the single exception of the time-to-intercept modulator, and provide field excitation to the automatic zero setting control motors and the time shared switch motor.

65. DERIVATION OF TACH X VOLTAGES

The voltage across the primary of T2 at any instant of time is the difference between the potentials of the applied phase A and B voltages at that instant. Figure 46 illustrates the phase relationship of these voltages. At time 1, phase A and phase B are of equal amplitude, and the potential across the primary of T2 is 0. At time 2, 30° later, phase A is 0, and phase B has an amplitude denoted by arrow a. At time 3, another 30° later, phase A is at some positive potential, and phase B is at some negative potential. The potential difference between the two is shown by arrow b, which is the potential applied across the primary transformer T2. At time 4, another 30° later, the difference in potential of phases A and B is maximum as shown by arrow c, and maximum voltage is applied across the primary T2. Thereafter, the voltages across the primary decreases until, at time 7, it is again 0, as the potential difference between phases A and B at that instant is 0. The negative half cycle of the voltage across T2 may be determined in a similar manner. As the relative polarity of phase A and phase B reverses at time 7, the phase of the potential difference between them also reverses at that instant. Inversion takes place in the stepdown transformer. The two signals present across the secondary are tach X1 and tach X2, each with an

distorted by nonlinear amplification. Each output has a 180° phase shift whenever the d-c control voltage changes polarity. Both outputs are applied to the amplifier phase inverter. The amplifier phase inverter uses a twin triode tube. One section operates as an amplifier, the other as a cathode follower. One output from the bridge is applied to the control grid of the amplifier (B) section and the other bridge output is applied to the control grid of the cathode follower (A) section. The signal from the cathode follower is then passed to the cathode of the amplifier. This input to the B-section is 180° out of phase with the input on the grid. The reaction of the amplifier is such that the two signals reinforce each other, correct any amplitude distortion, and produce an undistorted 400-cycle voltage output. Any output obtained from the amplifier phase inverter will be either in phase or 180° out of phase with the 400-cycle cathode excitation of the bridge stages. Harmonics present in both input signals to the amplifier are in phase and are about the same amplitude. As a result, they cancel each other. The output of the amplifier phase inverter is mixed with the negative feedback from the tachometer before the signal is applied to the low-power servoamplifier.

68. BALANCING NETWORK

The four tube sections that make up the balanced bridge are connected as in figure 48. A 400-cycle voltage is applied across the bridge through transformer T1, the secondary of which is tapped to the -250V supply. The primary of T1 is energized by 120-volt, 400-cycle, phase-AB power (tach X1 and tach X2). Inspection of figure 48 will show that the two A-sections of the tubes operate with a common plate load resistor, as do the two B-sections. The two sections of V1 operate with a common cathode resistor, as do the two sections of V2. The d-c control voltage from the DC amplifier is applied to the grids of V1A and V2B. The grids of the other two sections, V1B and V2A, are returned to the d-c potential present at the brush arm of MOD BAL control R23. The MOD BAL control compensates for slight differences in the transconductance of opposing sections of the bridge tubes. The d-c potential available from the brush arm must be of either polarity because the unbalance may lie in either direction. For this reason, R23 is connected in a voltage divider between +250V and -250V. The proper setting of the potentiometer is such that, in the absence of any d-c control voltage input, there will be no output from the modulator. This control is adjusted, in practice, to set the DC amplifier output to zero volts with a balanced input.

Section II. 400-CYCLE BALANCED MODULATOR

66. GENERAL (TM 9-5000-26)

The 400-cycle balanced modulator translates the positive or negative d-c control voltage received from the DC amplifier into a 400-cycle error signal, the phase and amplitude of which represent the polarity and magnitude of the d-c error. The signal inputs to the modulator are the d-c error voltage from the associated DC amplifier and 120-volt, phase AB cathode excitation voltage from the tach X1 and tach X2 supply. A d-c error signal 18.5 volts in magnitude will cause an rms output of about 0.1 millivolt, which is sufficient after passing through the low-power servoamplifier to drive the associated servomotor at full speed. The output is a 400-cycle voltage, 90° out of phase with mtr X (phase C). The circuit is similar to the acquisition radar AFC modulator stage already studied. Four of the five computer modulators are located in the rear bay of the right amplifier cabinet (page 6). The time modulator and all seven plotting board modulators are in the rear bay of the left amplifier cabinet. The modulator schematic is on page 31.

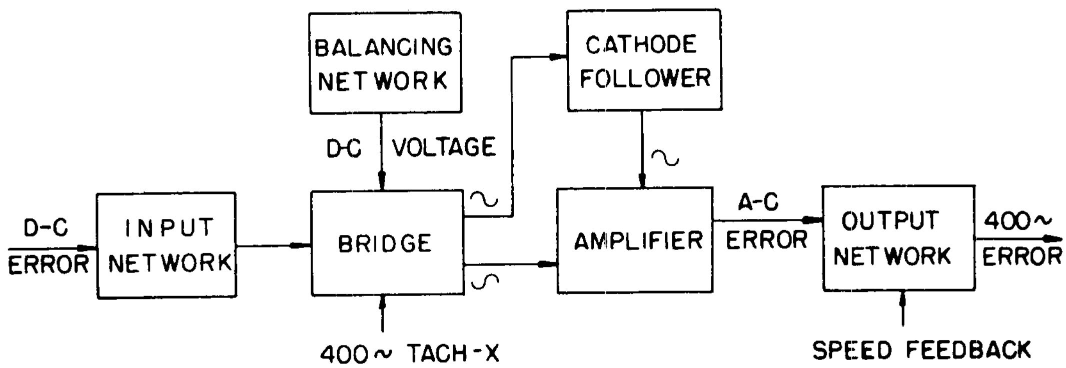


Figure 47. 400-cycle balanced modulator, block diagram.

67. SIMPLIFIED FUNCTIONAL OPERATION (fig 47)

In the 400-cycle balanced modulator, the input network receives the d-c error signal from the DC amplifier and passes it to the grids of the bridge tubes. The balanced bridge uses two twin triode tubes connected so that they operate as an electronic switch. A 400-cycle, a-c voltage is applied through a transformer to the cathodes of these tubes. The positive or negative d-c control voltage is passed by the input network and controls the switching action. The bridge produces two outputs 180° out of phase with each other. Each of these contains harmonics, the signal having been

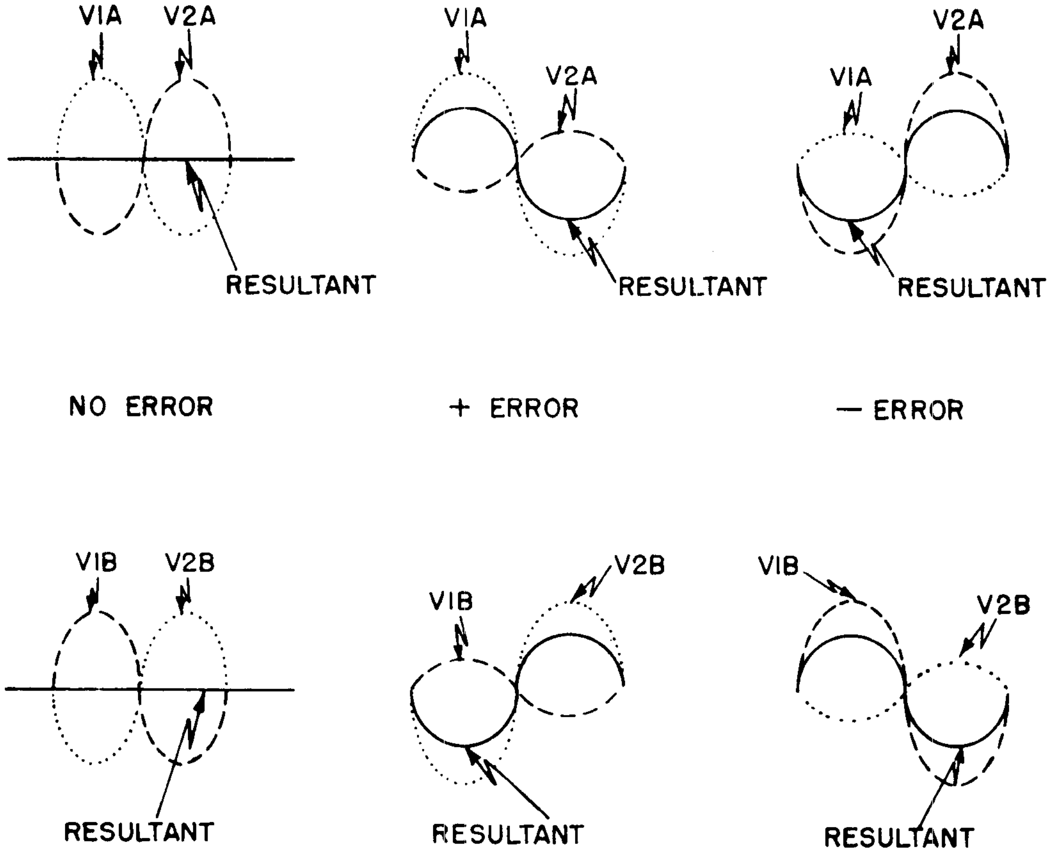


Figure 49. Ideal modulator bridge waveforms.

The voltage output obtained at the plates of the B-sections is determined by the current flow through R13. The current is contributed partly by V2B. As the 400-cycle signal at the cathode of V1B passes through its negative alternation, it causes an increase of current through V1B. At the same time, the signal at the cathode of V2B is decreased. The increase of current through V1B is equal to the decrease of current through V2B. The total current through plate-load resistor R13 is unchanged, and the output voltage remains constant.

70. BRIDGE OPERATION WITH A POSITIVE ERROR SIGNAL

The four sections of the modulator bridge do not operate on the linear portion of their characteristic curves, but near the knee of the curve. Because of this, the gain of the section increases when the d-c grid potential is made more

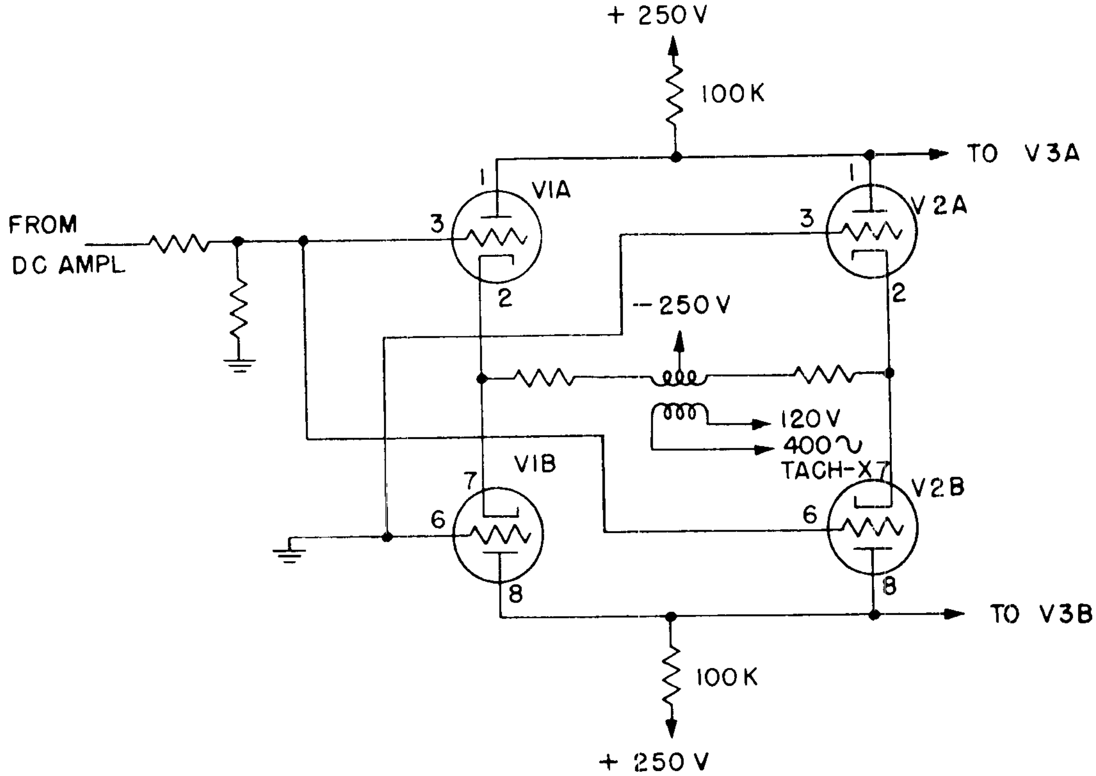


Figure 48. Balancing network circuitry.

69. BRIDGE OPERATION, ZERO ERROR SIGNAL

The 400-cycle voltages at opposing ends of the centertapped secondary of T1 are 180° out of phase. Therefore, the signal at the common cathode of V1 is 180° out of phase with the signal present at the common cathode of V2. With no d-c control voltage input, the conduction through the four tube sections balances. The signal that appears at the plate of V1A, as a result of its conduction, is in phase with the signal present at its cathode. Likewise, the signal at the plate of V2A, because of the conduction of V2A, is in phase with the signal present at the cathode of V2A. The signal at the plate of V1A is 180° out of phase with the signal at the plate of V2A because the signal at the cathode of V1A is 180° out of phase with the signal at the cathode of V2A. Without an error signal input, these plate signals are of equal amplitude, and because the plates are tied together, cancellation takes place. During this same period, the B-sections are operating similarly, and the 400-cycle signals are canceled in their plate circuit. Consider the action from another viewpoint. Resistor R13 is the common plate-load resistor for the two B-sections.

71. BRIDGE OPERATION, NEGATIVE ERROR SIGNAL

Application of a negative d-c signal from the DC amplifier to the control grids of V1A and V2B will reduce the gain of those two sections. In a manner similar to that explained in the preceding paragraph, the gain of V1A and V2B will be made to increase. An output signal will appear in the plate circuit of the A-sections which will be in phase with the 400-cycle voltage present at the cathodes of V2. An output signal of opposite polarity will appear in the plate circuit of the B-sections. Note that the output signals obtained as a result of the negative d-c control voltage are opposite in phase to those obtained as a result of a positive d-c control voltage.

72. BRIDGE WAVEFORMS

a. Idealized waveforms are illustrated in figure 49. Conditions of no error signal, positive error signal, and negative error signal are shown.

b. The bridge tube introduce considerable distortion because they do not operate linearly. Because of this distortion, the actual waveforms differ from those illustrated in figure 50. The harmonics present in each output lead are in phase, making it possible to eliminate them in the following stage, the amplifier phase inverter.

73. AMPLIFIER PHASE INVERTER (fig 51)

This stage uses a twin triode tube. Two inputs are used to obtain a single output. The push-pull 400-cycle output of the bridge is the input to the amplifier phase inverter. The signal applied to the A-section (cathode follower) is 180° out of phase with the signal applied to the grid of the B-section (amplifier). Cathode coupling is used to apply the signal from the A-section to the B-section. This cathode-coupled signal is of the same phase and approximate amplitude as the signal applied to the grid of the A-section. The B-section thus receives two inputs, one to grid and one to cathode, of opposite phase. The output of the amplifier phase inverter is taken from the B-section. This signal will be in phase with the input on the cathode and 180° out of phase with the input at the grid. The 400-cycle plate output will be greater in amplitude than either input to V3, and will agree in phase with the input to the A-section.

74. DISTORTION (fig 52)

Harmonics present in the output of the bridge are in phase at the two grids of V3. The harmonics applied to the grid of the A-section appear at the cathode

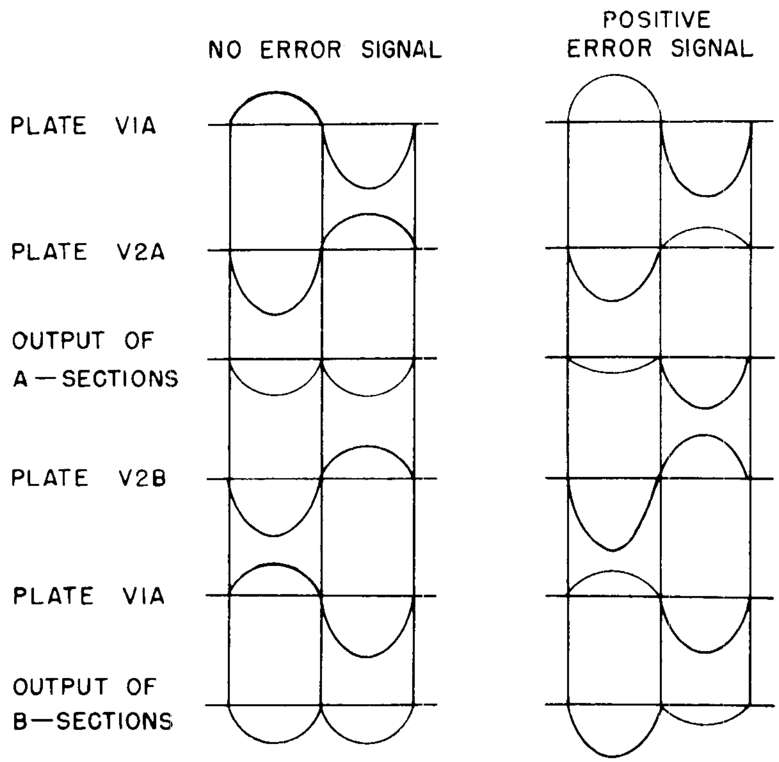


Figure 50. Actual modulator bridge waveforms.

positive and decreases when the grid voltage is made more negative. Application of a positive control voltage to the grids of V1A and V2B causes the gain of these two sections to increase. A greater average current will flow through V1A and V2B, developing a higher average voltage across the cathode resistors. The more positive cathode potentials increase the bias and reduce the gain of the other sections, V1B and V2A. The gain of V1A is now greater than the gain of V2A, and the gain of V2B is greater than the gain of V1B. The signal appearing at the plate of V1A as a result of the conduction of V1A will now be of greater amplitude. The signal appearing at the plate of V2A as a result of the conduction of V2A will be of reduced amplitude. Complete cancellation will not take place. Instead, a signal will be present in the plate circuit of the A-section, which will be in phase with the 400-cycle voltage at the cathodes of V1. Similarly, an output signal will be present in the plate circuit of the B-sections. Because of the increased gain of V2B and the reduced gain of V1B, this signal will be in phase with the 400-cycle voltage present at the cathodes of V2. The two output voltages are therefore push-pull signals, 180° out of phase.

of the B-section in phase with the harmonics present at the grid of the B-section. The degenerative effect is enough to eliminate the harmonics present in the signals applied to V3 almost entirely. Capacitor C3, connected between the plate of V3B and ground, provides a shunt for further correction. The reactance of this capacitor at the desired 400-cycle frequency is approximately 40,000 ohms. At the higher frequencies characterisitc of the harmonics, the reactance is considerably less. A larger value of capacitance would function more efficiently as a filter, but the resulting attenuation of the error signal would be undesirable. Capacitor C4 and resistors R15, R16, and R19 form the output network. Capacitor C4 couples the 400-cycle error signal to the mixing circuit. Resistors R16 and R19 are of the same value; they mix the error signal with feedback from the generator. This speed feedback from the generator is developed across R15. The resulting voltage at the junction of R16 and R19 is the output of the 400-cycle balanced modulator. It is sent to the low-power servoamplifier.

Section III. LOW-POWER SERVOAMPLIFIER

75. GENERAL (TM 9-5000-26)

The low-power servoamplifier amplifies the 400-cycle error signal received from the 400-cycle balanced modulator to a power level sufficient to drive the servomotor. The signal input is the 400-cycle error voltage from the balanced modulator. A 0.1-millivolt input is raised in power level enough to drive the servomotor at full speed. The over-all gain is approximately 50,000. Such a high degree of amplification makes the closed loop control system quite sensitive to small errors. The output is a 400-cycle driving voltage, 90° out of phase with phase C (mtr X), which is transmitted to the servomotor. Twelve low-power servoamplifiers are used in the computer, one with each servo circuit. They are located adjacent to the associated modulator in the rear bays of the amplifier cabinets (page 6). There are no adjustments to be made in the unit. The schematic of the low-power servoamplifier is found on page 33.

76. SIMPLIFIED FUNCTIONAL OPERATION (fig 53)

The low-power servoamplifer consists of four stages: two voltage amplifiers, a paraphase amplifier, and a push-pull power amplifier. Negative feedback is used twice within the unit. The first use is to provide stability in the voltage amplifiers and the second is to cancel harmonics introduced by tachometer feedback. The two voltage amplifiers are contained in a single high-mu tube.

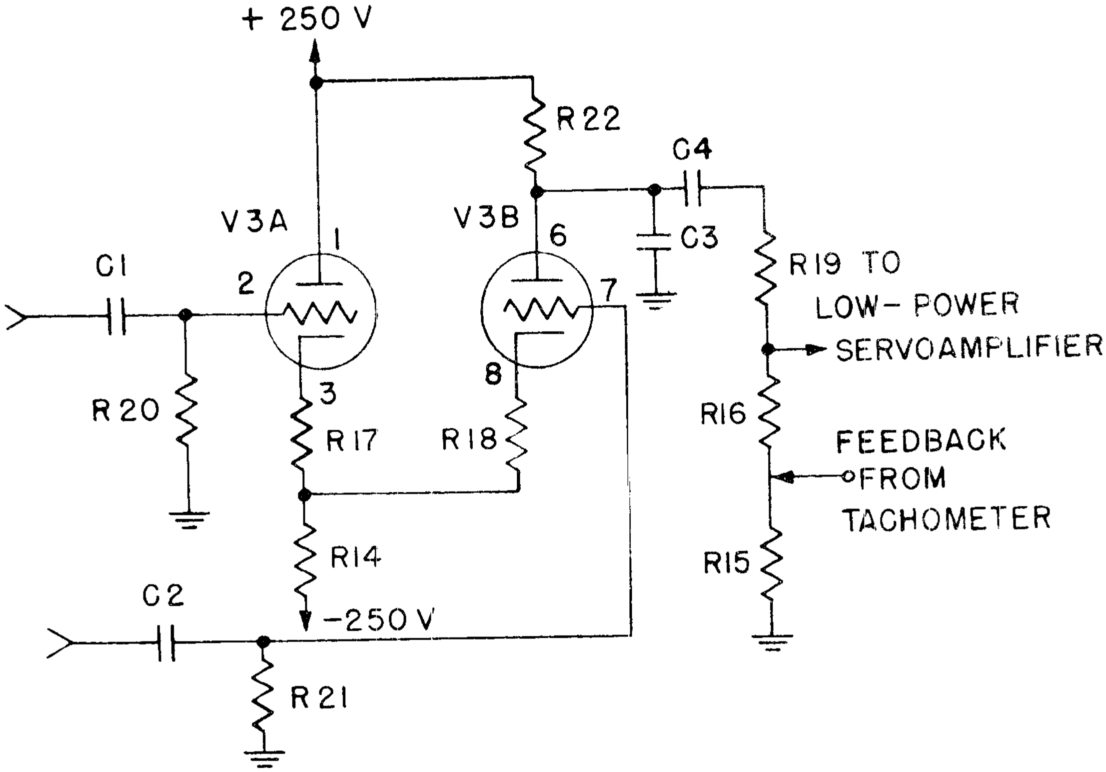


Figure 51. Amplifier phase inverter, simplified schematic.

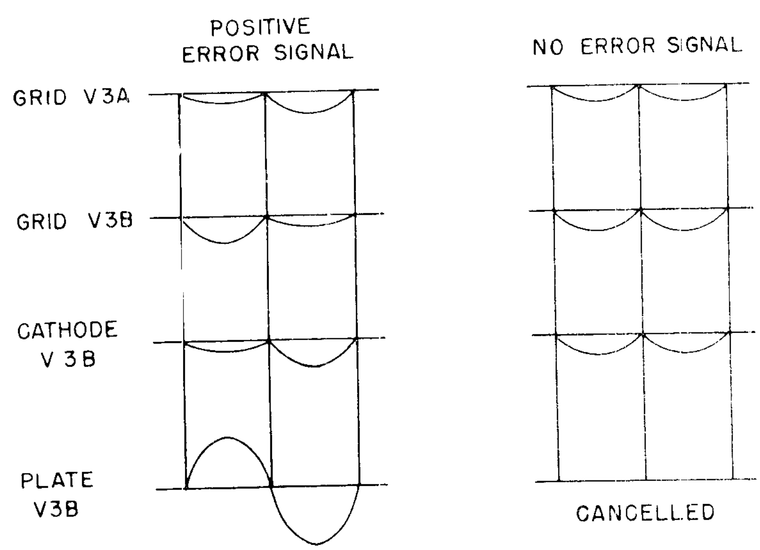


Figure 52. Amplifier phase inverter waveforms.

387282 O - 56 - 5

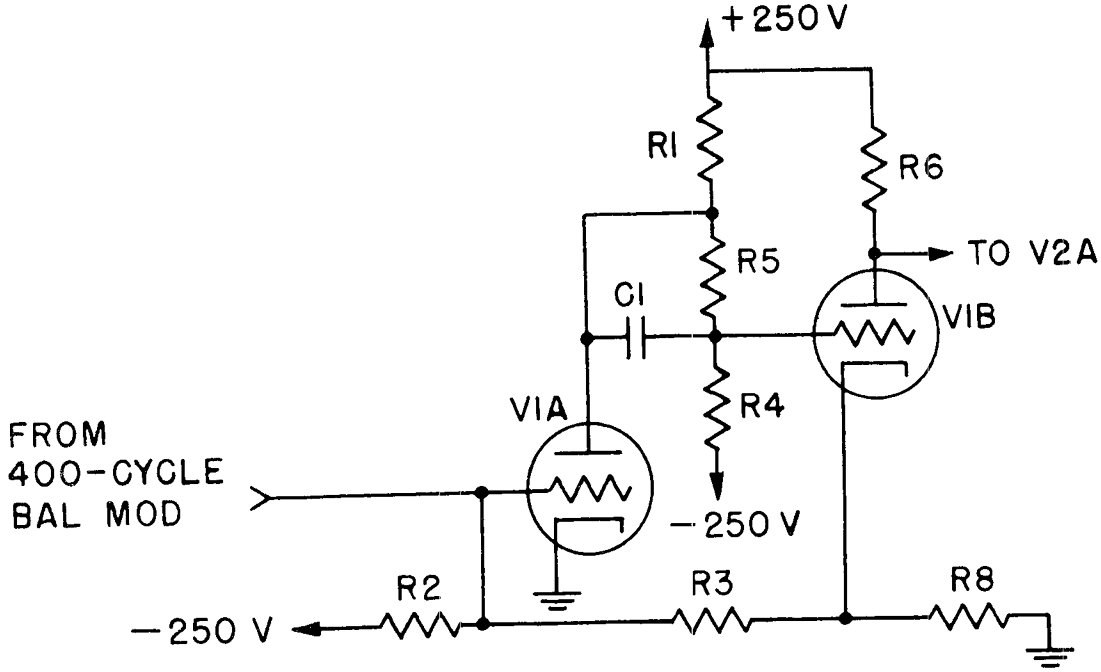


Figure 54. Voltage amplifiers, simplified schematic.

It transmits any voltage change occurring at the plate of V1A instantaneously and at full value to the control grid of V1B. Negative feedback goes from the cathode of V1B to the grid of V1A. The feedback overcomes any tendency of this high-gain amplifier to oscillate. During the no-signal period, current through V1A is approximately 0.5 ma, and through V1B approximately 1.0 ma. This current flow through the two stages must be considered in determining the magnitude of the various operating voltages. Should the current through V1B increase, the cathode would become more positive. This voltage rise would be coupled to the grid of V1A and cause a drop in voltage at the plate of V1A. This plate drop would be coupled through C1 to the grid of V1B and would reduce the current through V1B to the original value. A decrease in current through V1B would be corrected in a similar manner. Thus, the effect of the negative current feedback is to resist any change in current through V1A or V1B. In attempting to maintain a constant current, the amplifier will present an apparent high output impedance. The amplification possible with this type of circuit is not great because of the negative feedback used. Amplification is sacrificed in favor of stable operating characteristics. The output of V1B is coupled through C3 to the grid of V2A in the paraphase amplifier.

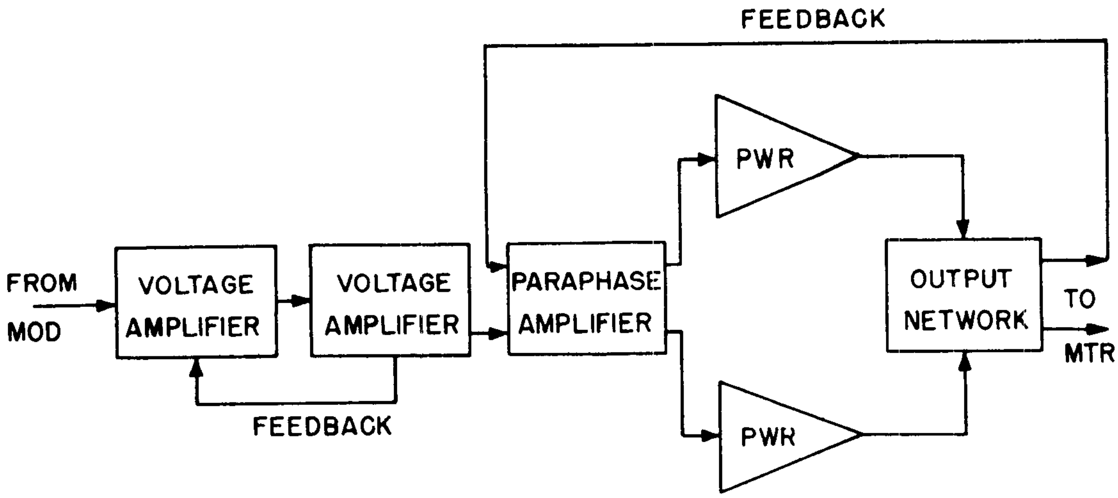


Figure 53. Low-power servoamplifier, block diagram.

They provide amplification of the 400-cycle signal received from the 400-cycle balanced modulator. Negative feedback between the two stages greatly reduces the amplitude of the input. If the input signal were monitored with a test oscilloscope at the control grid of the first stage, it would appear as an extremely weak 400-cycle voltage because of the feedback. The paraphase amplifier receives the output of the voltage amplifiers and produces two outputs equal in amplitude but opposite in phase. The paraphase amplifier is conventional in circuitry and uses a single high-mu twin triode. The two outputs are required for the operation of the push-pull power amplifier. They are applied to the control grids of the two pentodes which make up the output stage of the servoamplifier. These pentodes are high-current tubes, operated as a class AB amplifier, supplying enough output power to drive the servomotor. The 400-cycle output signal is applied directly to the control-field winding of the servomotor.

77. VOLTAGE AMPLIFIERS V1A AND V1B (fig 54)

The output of the 400-cycle balanced modulator is applied directly to the grid of V1A. Tube sections of V1A and V1B are connected as conventional R-C coupled voltage amplifiers. Bias is developed at V1A by voltage divider R2-R3-R8, connected between the negative 250-volt supply and ground. Resistor R8 also serves as the cathode resistor for V1B. Bias is developed at V1B by voltage divider R1-R5-R4, connected between +250V and -250V. Resistor R1 also serves as the plate-load resistor of V1A. Plate resistor R6 of V1B operates as part of a bridged-T network. Capacitor C1 couples V1A and V1B.

equal in amplitude are applied between grid and cathode of the two sections. A balanced push-pull output signal is obtained to be fed to the grids of the power amplifier.

79. POWER AMPLIFIER V3 AND V4

The push-pull 400-cycle output of the paraphase amplifier is coupled to the grids of V3 and V4 through capacitors C4 and C5 and an R-C filter. This stage, illustrated in figure 56, consists of two pentodes which are operated class AB. Bias is developed across the common cathode resistor. Parasitic oscillations are suppressed by the 47-ohm resistors in the grid and plate circuits. Harmonics at frequencies above 400 cycles are shunted by the R-C filter composed of R20 and C8. The impedance of this filter is high at 400 cycles, but at higher frequencies it decreases sharply. This reduction of impedance introduces increasing attenuation at the frequencies of higher harmonics. The output is developed across transformer T1 by currents flowing alternately through each tube and through half of the primary of T1. Since both tubes operate class AB, each tube conducts for slightly more than half of each cycle. For a part of each half cycle, bucking currents flow in the primary of T1. Appreciable power loss as a result of these bucking currents is avoided by use of a plate supply voltage which is the unfiltered output of a full-wave rectifier, as shown in figure 57. This supply voltage is obtained from the -270V supply. The peak voltage amplitude attained each half-cycle is 420 volts. The average voltage ($E_{pk} \times \frac{2}{\pi}$) is 270 volts. The a-c input to the +270V power supply is in phase with the 400-cycle voltage applied to the balanced modulator (phase AB). As the plate-supply voltage for tubes V3 and V4 reaches its peak of +420 volts, the error signal present at one grid is at its maximum negative point. At this instant, maximum power is delivered by the stage. At an instant when the push-pull error signals at the control grids are at or near the zero value, both tubes are allowed to conduct. At this time, however, the plate-supply voltage is at or near zero. The amplitude of opposing currents that may flow in the primary of T1 is therefore very small, and the power loss is minimized. The current in the primary of T1 is produced by the alternate conduction of the two tubes, and a 400-cycle error signal is developed across the secondary of the transformer. Since this output signal will be applied across an inductive load consisting of the control-field winding of the servomotor, capacitance must be added to the circuit to avoid a phase shift. This phase shift correction is made by C6 and C7. Maximum power output of the stage is about 10 watts.

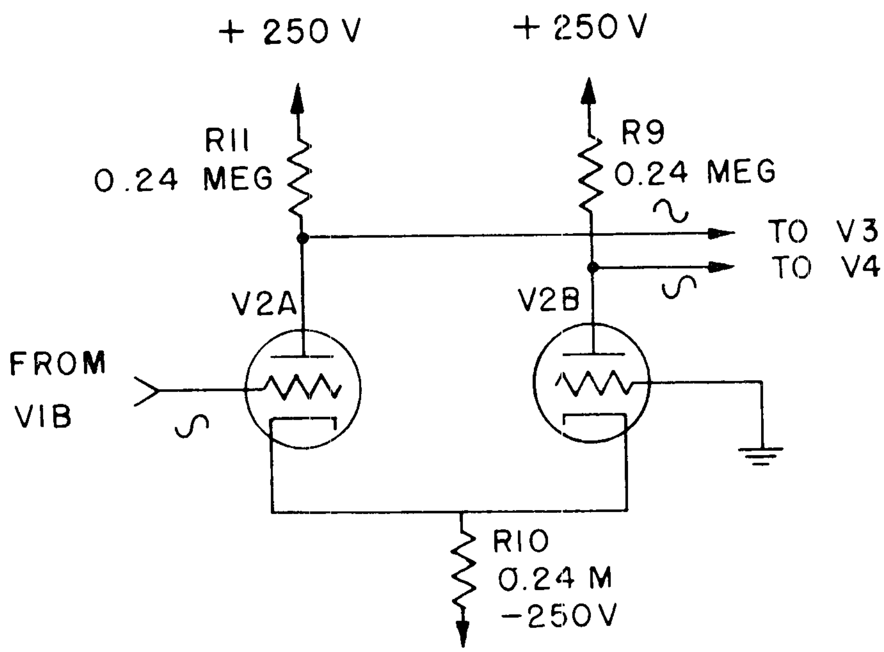


Figure 55. Paraphase amplifier, simplified schematic.

78. PARAPHASE AMPLIFIER V2 (fig 55)

Tubes V2A and V2B form a conventional two-tube, cathode-coupled paraphase amplifier. Section V2A operates as an amplifier. Section V2B is used as another amplifier to produce a signal of the same amplitude as the output of V2A, but of opposite polarity. Since common cathode resistor R10 is not bypassed, the voltage that appears across it is the resultant of the two plate currents, having the same shape and polarity as the voltage applied to the grid of V2A. This action is similar to that which takes place in a cathode follower, but it differs in two important respects: the output from the stage is taken from the plate so that, although the voltage developed across R10 is degenerative, the gain is not limited to less than unity; and the plate current of both tubes flows through R10. The value of R10 has been selected so that the amplitude of the degenerative voltage developed across it is equal to half of the voltage applied to the grid of the A-section. The effective signal voltage that appears between grid and cathode of the A-section is half of the applied voltage. The signal voltage at the cathode is also equal to half of the applied voltage. As the grid of V2B is connected to ground, application of this voltage to the cathode has the same effect as would be obtained by applying a voltage of opposite polarity to the grid. As a result, signals opposite in polarity but

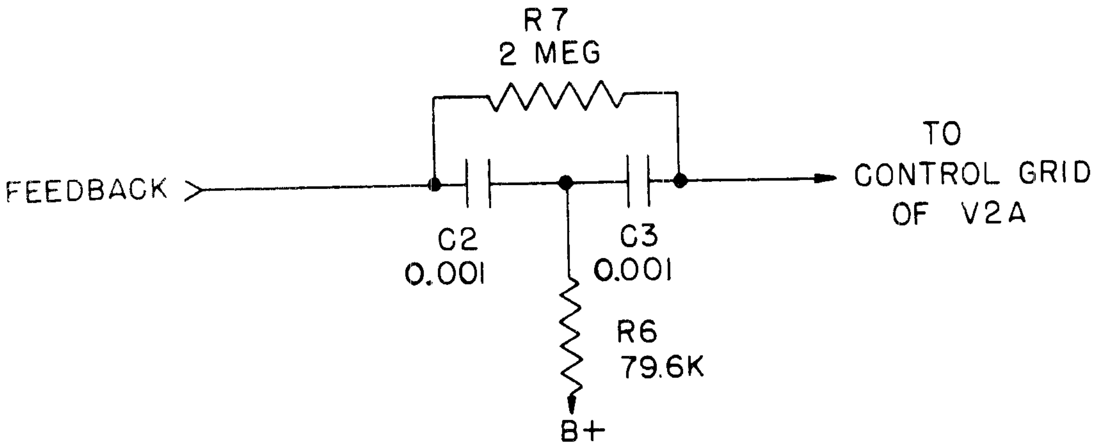


Figure 58. Bridged-T network, simplified schematic.

80. BRIDGED-T NETWORK (fig 58)

Undesirable frequencies, the most pronounced of which is the third harmonic, are introduced into the system principally through the feedback voltage from the tachometer. A conventional negative feedback circuit which would introduce sufficient degeneration to eliminate these frequencies would result in serious attenuation of the desired 400-cycle error signal. The bridged-T network is a frequency selective network. The components of the bridged-T network are C2, C3, R6, and R7. The values of these elements have been selected so that negative feedback is attained only at frequencies above or below 400 cycles. Minimum feedback will occur for signals of 400 cycles. The desired amplitude of feedback voltage is obtained by means of the voltage divider consisting of R21 and R22. From the junction of these two resistors, the feedback signal is applied to the bridged-T network at the junction of C2 and R7. A possible path for the signal is through R7. However, at 400 cycles the impedance of C2 is considerably less than that of R7. The major portion of the signal takes the path of least impedance, appearing at the junction of C3 and R6. At 400 cycles, the impedance of R6 is less than that of C3, and the 400-cycle feedback signal is prevented from appearing at the grid of V2A. Instead, it is shunted to ground through the power supply. A feedback signal at a frequency considerably above or considerably below 400 cycles would be applied to the control grid of V2A. Assume a subharmonic feedback signal of 40 cycles. At the junction of C2 and R7, this signal would meet lower impedance through the 2-megohm resistor than through the capacitor, and the signal would then appear at the control grid of V2A. A harmonic at a frequency of 4,000 cycles at the junction of C2 and R7 would see a lower impedance through the capacitor than through the resistor. As a result, the signal would

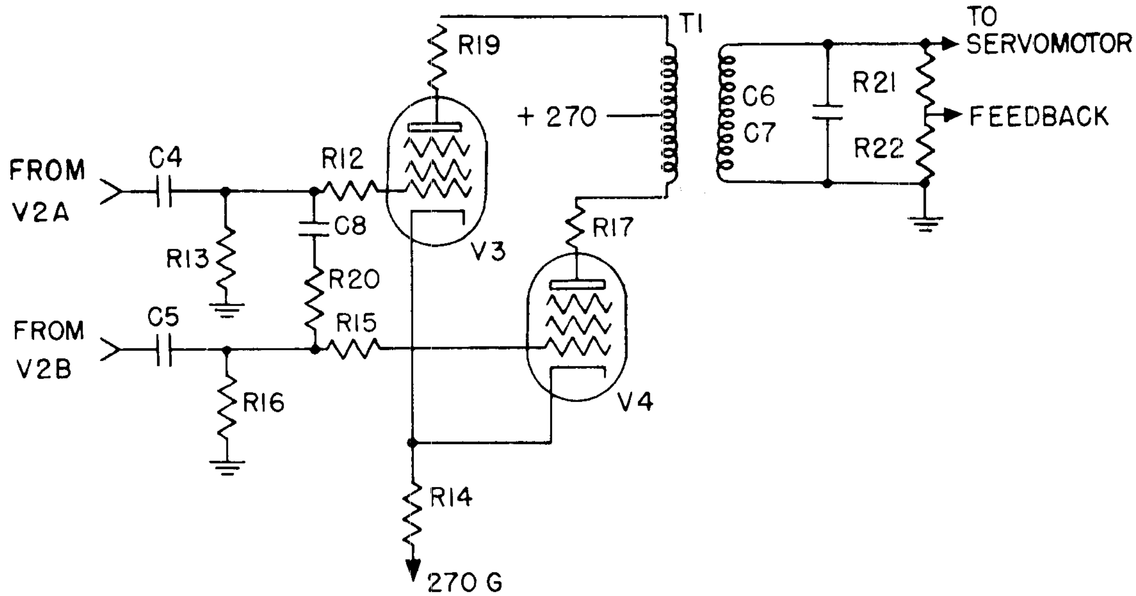


Figure 56. Power amplifier, simplified schematic.

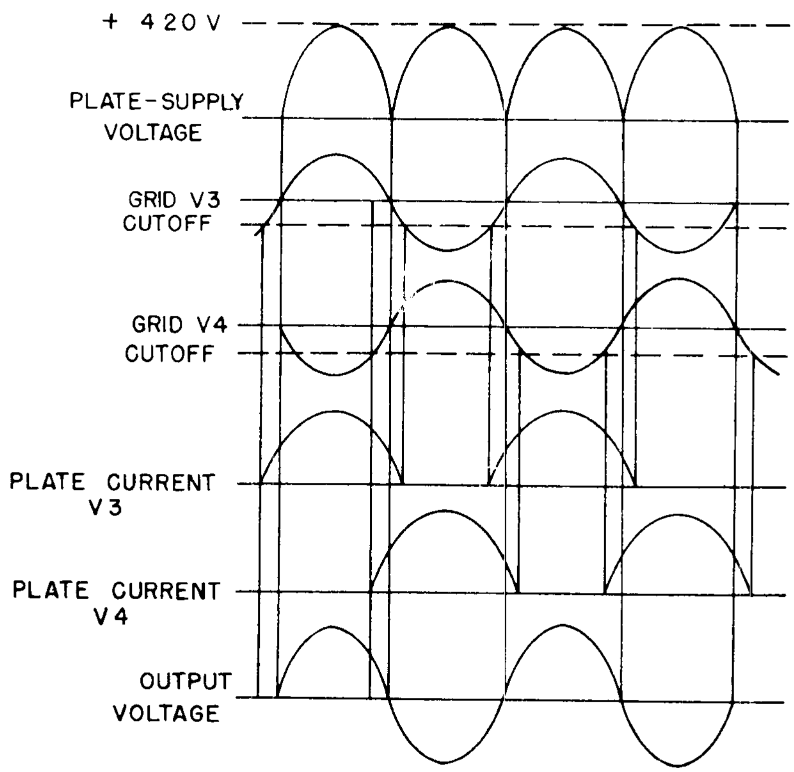


Figure 57. Power amplifier waveforms.

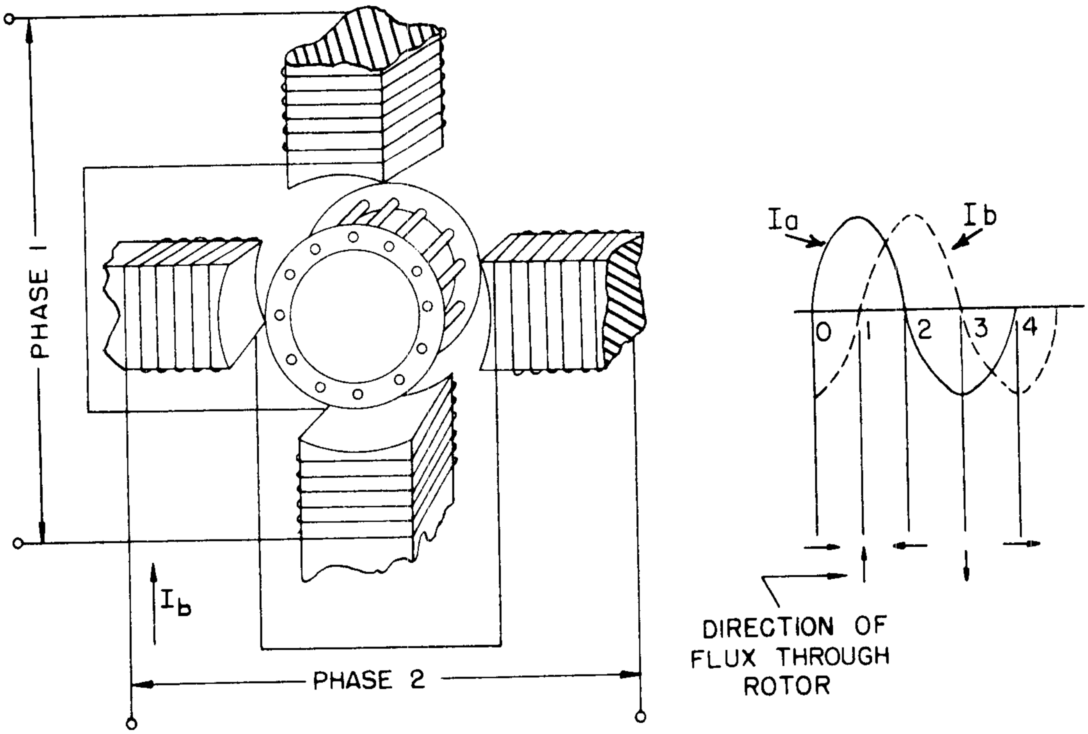


Figure 59. Squirrel-cage motor, simplified.

maximum positive value, Ib is zero, and the field is directed upward. At time 2, Ia is again zero, Ib is at maximum positive value, and the flux is directed horizontally to the left. The application of two sine wave voltages to the field windings of the servomotor will cause a rotating magnetic field to exist in the action space between the pole faces. As the rotating field cuts the bars (conductors) of the rotor, currents will flow in the rotor. The direction of the resulting force which will act upon the bars may then be determined by the right hand rule. This force rotates the rotor. Torque is dependent upon the rotor bars being cut by the lines of force of the rotating magnetic field. For this reason, the rate of rotation of the motor must be less than that of the magnetic field. This difference in the speed of rotation is the slip of the motor. As the load on the motor is increased, the speed of rotation of the motor is decreased. This increases the slip and causes larger currents to be induced in the rotor bars. These large currents result in a greater torque being developed, enabling the motor to drive the increased load. Too great a load will induce larger currents than the motor is built to handle and will result in a burned-out unit.

next appear at the junction of C3 and R6. Again, the capacitive path offers the lower impedance. The feedback would be applied to the control grid. The gain of the low-power servoamplifier at any frequency is proportional to the attenuation experienced by that frequency in the bridged-T network.

Section IV. SERVOMOTOR

81. GENERAL (TM 9-5000-26)

The purpose of the servomotor is to respond to the error signals received from the low-power servoamplifier to produce mechanical rotation in the proper direction. Five of these units are located in the servo assemblies of the servo cabinet. The remaining seven are attached to the plotting boards for positioning the pens. The generator is within the same casing as the motor. A very general picture of the motor-generator assembly and connections can be seen on page 161. Motor excitation (120 volt, 400-cycle, phase C) is always brought to terminals 3 and 4. The control voltage from the low-power servoamplifier (400-cycle, phase AB) is always brought to terminals 1 and 2. If the driving and excitation voltages are not connected to the proper terminals, the driven components will move in reverse. There are no adjustments made to the servomotor.

82. OPERATION

The servomotor is a 2-phase, a-c induction motor powered by 2 a-c voltages, 90° out of phase with each other. This motor consists of a stationary field structure and a rotating element. The stator of the motor has two field windings displaced 90° from each other. During operation, one coil is continuously excited by mtr X. The other coil receives the output of the low-power servoamplifier. This control voltage has a phase relationship of either 90° or 270° with mtr X. A reversal in the phase of the voltage applied to the second coil will reverse the direction of rotation of the servomotor. Through a system of gearing, the motor controls the position of potentiometer contact brushes, switch cams, and indicator dials. The motor is of the squirrel-cage type (fig 59). The name is derived from the resemblance of the rotor to a squirrel cage. This rotor consists of copper bars welded to end rings and imbedded in iron laminations. The windings of the vertical pole pieces are connected to one phase and the windings of the horizontal pole pieces are connected to the other phase. The currents through these windings are designated as Ia and Ib in figure 59. At the instant indicated by time 0 on the curves, Ia is zero, and Ib is at maximum negative value. The lines of flux through the rotor are directed horizontally to the right. At time 1, a quarter cycle later, Ia is at

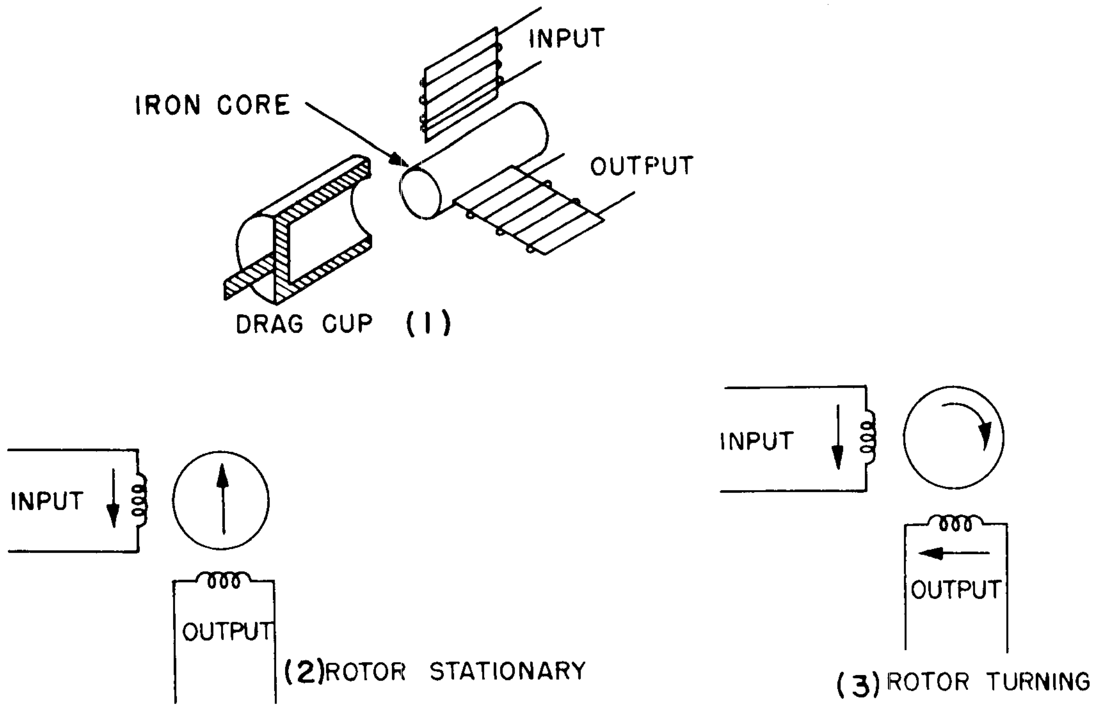


Figure 60. Generator, simplified.

by the current in the input coil. However, eddy currents are produced in the rotor cup because of the changing magnetic field. The rotor surface may be considered as an infinite number of shorted conductors, such as those in a squirrel-cage rotor. When the rotor is turned, these conductors cut the magnetic flux created by the current in the input winding, and current flows in the rotor. This current in the rotor generates a second magnetic field which distorts the original field to produce a resultant field. The magnitude and direction of the resultant field are dependent upon the speed and direction of rotation of the rotor. In an induction motor, the rotating stator field drags the rotor conductor. In the generator, the rotor conductors may be considered as dragging the stator field. For this reason, the rotor is called the drag cup. When the stator field is dragged, or distored, the angle existing between the resultant field and the output winding is no longer 90°. Consequently, the lines of flux cut the output winding and induce in it a voltage with a phase and amplitude dependent upon the direction of rotor rotation. When the servomotor reverses direction, the rotor of the generator also reverses direction. The output then undergoes a 180° phase reversal. The output voltage is always degenerative at the point where it is introduced to the a-c error voltage. One disadvantage of this type of generator is that the eddy

Section V. FEEDBACK GENERATOR

83. GENERAL

The generator generates a 400-cycle, a-c voltage with an amplitude proportional to the speed of rotation of the servomotor, and 180° out of phase from that of the error signal from the balanced modulator. The generator is a small, 400-cycle, a-c generator built on the induction principle. It is contained within the servomotor housing, and is driven by the rotor of the servomotor. It is used because of its low inertia, low power demand, and ease of maintenance. One of its windings is energized by tach X in phase with that voltage applied to the cathodes of the balanced modulator. It generates a 400-cycle voltage that is always 180° out of phase with the error voltage output of the amplifier phase inverter of the balanced modulator. The output of the generator is applied as negative feedback to the output network of the modulator. The generator produces an output only when the servomotor rotates. The amplitude of the generated voltage increases with an increase in the speed of rotation of the servomotor. The phase of the generated voltage is dependent upon the direction of rotation of the servomotor. Generator feedback opposes and effectively reduces the error signal that controls the servomotor. This effect is called speed feedback damping. When the error signal is eliminated, generator feedback serves as a braking signal to stop the servomotor. The voltage generated by the generator contains undesired third harmonics at a 1,200-cycle frequency. The bridged-T network in the low-power servoamplifier eliminates this third harmonic.

84. OPERATION

Eddy currents which are excited in a hollow cylindrical rotor induce a voltage in a secondary winding. Eddy currents are currents produced by an emf induced in a conductor when the conductor is moved in a magnetic field, or when a magnetic field in which the conductor is located changes in intensity. These currents are usually small. The induced voltage is at right angles to the magnetic lines of force. The stator of the generator has two windings displaced 90° from each other (fig 60). One of these windings is the input winding, and the other is the secondary output winding. A core of soft iron is centered in the space which would be occupied by the rotor of a conventional generator. Enough space is left between the stator and the core to permit the rotation of a hollow cylindrical rotor. The rotor is driven by a shaft connected to the closed end. The input coil is excited by tach X. The a-c current creates an alternating magnetic flux which is directed and confined by the soft iron core. As long as the rotor is stationary, no output voltage is developed. This is because the secondary winding is perpendicular to the magnetic field created

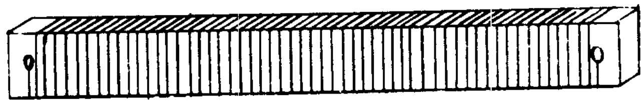


Figure 61. Simple potentiometer card.

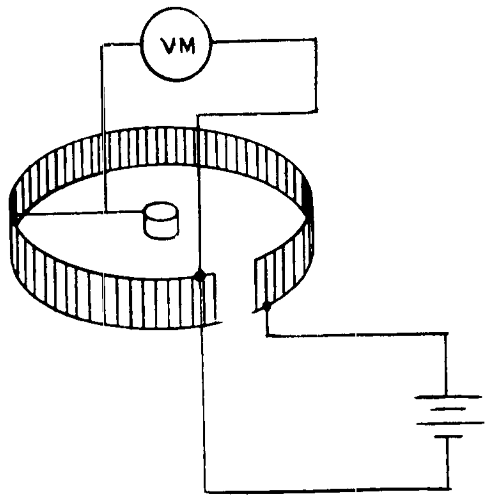


Figure 62. Card bent into an arc.

wire is wound on an insulating strip called a resistance card. The potentiometers used in the computer are cards bent to form an arc of nearly 360° (fig 62), and mounted so that the slider makes contact with the winding along one edge of the strip. The slider is usually able to rotate continuously, but it loses contact with the resistor over a small arc. In servo usage, the potentiometer should be thought of as a variable-voltage source rather than as a variable resistor, in that an input voltage is applied to the resistance element, and a fraction of this voltage appears as an output between the slider and one end of the resistance. Unfortunately, the output of a potentiometer does not change smoothly as the slider is moved. Instead, the output voltage changes in jumps, each jump being equal to the voltage difference existing between adjacent turns of wire. This effect is known as granularity. The degree of granularity determines the resolution of a potentiometer. A potentiometer having 1,000 turns of wire on the resistance element is said to have a resolution of 1 part in 1,000 or a resolution of 0.1 percent, which means that the smallest change in

currents generated in the aluminum cup cause harmonics to appear in the output voltage. These harmonics, if not eliminated, would cause power loss and overheating of the servomotor. It is important that the output voltage be exactly 180° out of phase with the output signal of the balanced modulator. The design of the generator is such that the phase of the generated output voltage is accurate within a 1° tolerance. A variable resistor is placed in series with the energized stator coil. Adjustment of this control will produce enough phase shift to obtain an output of the exact phase required from the circuit. This phasing is a job normally done by ordnance shops with the necessary equipment for such accurate work. If the adjustment becomes unavoidable in the field, the easiest way for an approximate setting is to adjust the control for a minimum reading on an a-c voltmeter across the output terminals of the 400-cycle balanced modulator. Be certain that a fairly large constant error is driving the closed loop control system at the time of adjustment, or else the setting will not even be an approximation.

Section VI. POTENTIOMETERS

85. GENERAL

The Nike I computer is a d-c analog computer. In such a computer, physical measurements such as distances, velocities, acceleration, time, and angles are represented in one of two ways: as a d-c voltage, which is proportional to the physical quantity; or as a shaft position, which is proportional to the physical quantity. In either case, the representative voltage or shaft position (which is the analog) is related to the physical quantity by a scale factor. Thus, a distance of +1,000 yards could be represented by a voltage of +1 volt or by a displacement (from zero reference position) of 1,000 mils. In the first case, the distance is represented by a voltage at the scale factor of 1 millivolt per yard; in the second case, it is represented by a shaft position at the scale factor of 1.0 mil per yard. The Nike I computer uses both means of representation and requires frequent conversion from one representation of a quantity to the other. The potentiometer which is described in the succeeding paragraphs is the device that is used for converting a shaft position (the mechanical analog) into a voltage (the electrical analog). The opposite conversion, from a voltage to a shaft position, is done by a servo. Servo systems are discussed section VIII.

86. POTENTIOMETER CARDS

Most potentiometers used in servos are similar, consisting of wire resistors and movable sliding contacts. In the conventional type (fig 61), the resistance

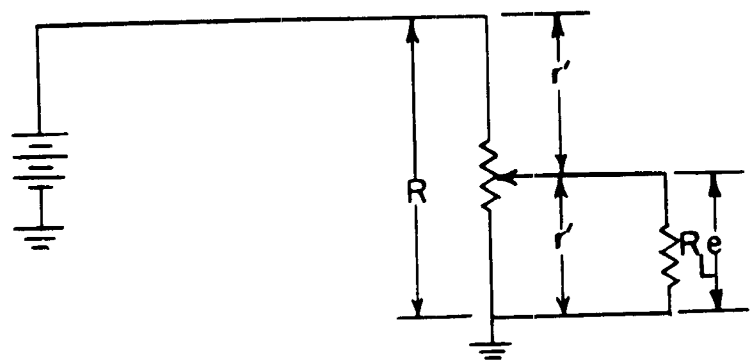


Figure 64. Potentiometer and load.

Any intermediate position of the brush arm will tap a potential which is proportional to the physical values within the specified maximum range of time.

88. SCALE FACTORS

The proportionality or ratio between the voltage applied to the potentiometer and maximum specified range is usually expressed in terms of a decimal fraction of volts per yard. In the case of +100 volts applied to the potentiometer to represent a 100,000-yard maximum range, the potential corresponding to 1 yard would be 1 millivolt, or, in other words, a scale factor of 1 millivolt per yard. The scale factor determines the voltage that must be applied to a potentiometer to represent values of a desired maximum range. Conversely, with a given d-c voltage, the scale factor will determine the maximum range that the potentiometer can cover. The functional schematics used to present the circuit operation of the computer contain symbols such as X_T and S_Y, which represent physical quantities in yards. The voltage analog of the symbol is always obtained by multiplying the physical quantity in yards by the scale factor. The significance of the foregoing statement is that the voltage analog of the physical quantity is always proportional to the physical quantity itself.

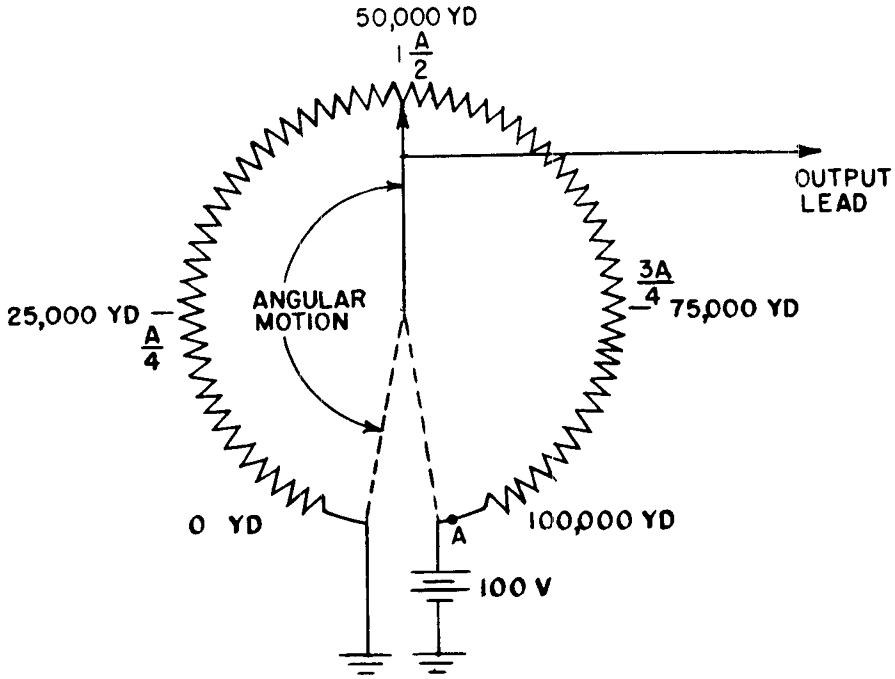


Figure 63. Potentiometer used to represent distance.

the output voltage is 1/1,000th of the input voltage. To improve the resolution (make the voltage jumps smaller), the number of turns on the card is sometimes increased and the voltage change from turn to turn approaches a smooth curve.

87. REPRESENTATION OF DISTANCE OR TIME WITH VOLTAGE DIVISION

Potentiometers that operate with a linear characteristic can be used for range and time representation, if the voltage applied to the resistance element is made proportional to a specified maximum range or time. For example, in figure 63 +100 volts d-c is applied to the resistance element terminals to represent either a range of 100,000 yards or 100 seconds of time. When the brush arm has a zero displacement from the reference terminal (ground), the potential tapped is zero; when the brush arm is moved to full angular displacement (A), the potential tapped will be +100 volts, which represents 100,000 yards range or 100 seconds of time. Similarly, at one-quarter angular displacement ($\frac{A}{4}$) the potential tapped will be +25 volts, which is 25,000 yards or 25 seconds; at one-half angular displacement ($\frac{A}{2}$) the 50 volts tapped represents 50,000 yards or 50 seconds; at three-quarters ($\frac{3A}{4}$), 75,000 yards or 75 seconds.

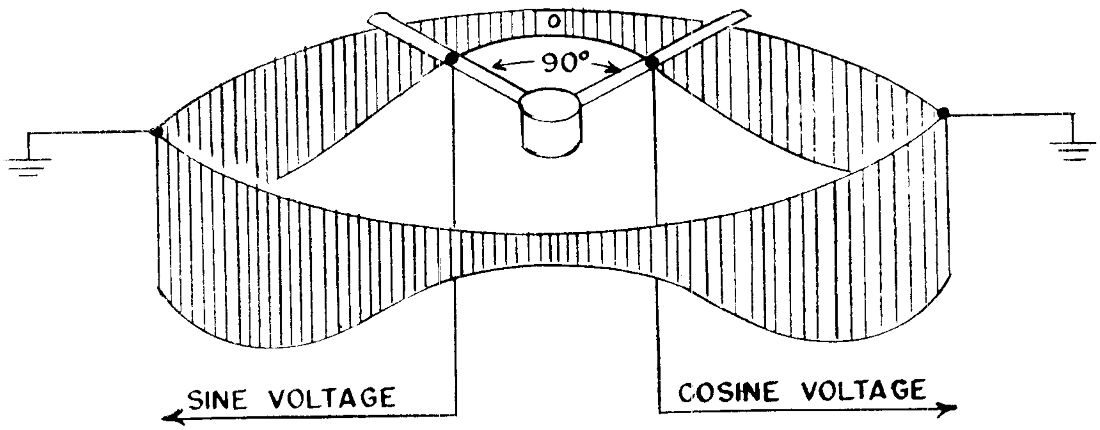


Figure 65. Physical appearance of a sine-cosine potentiometer.

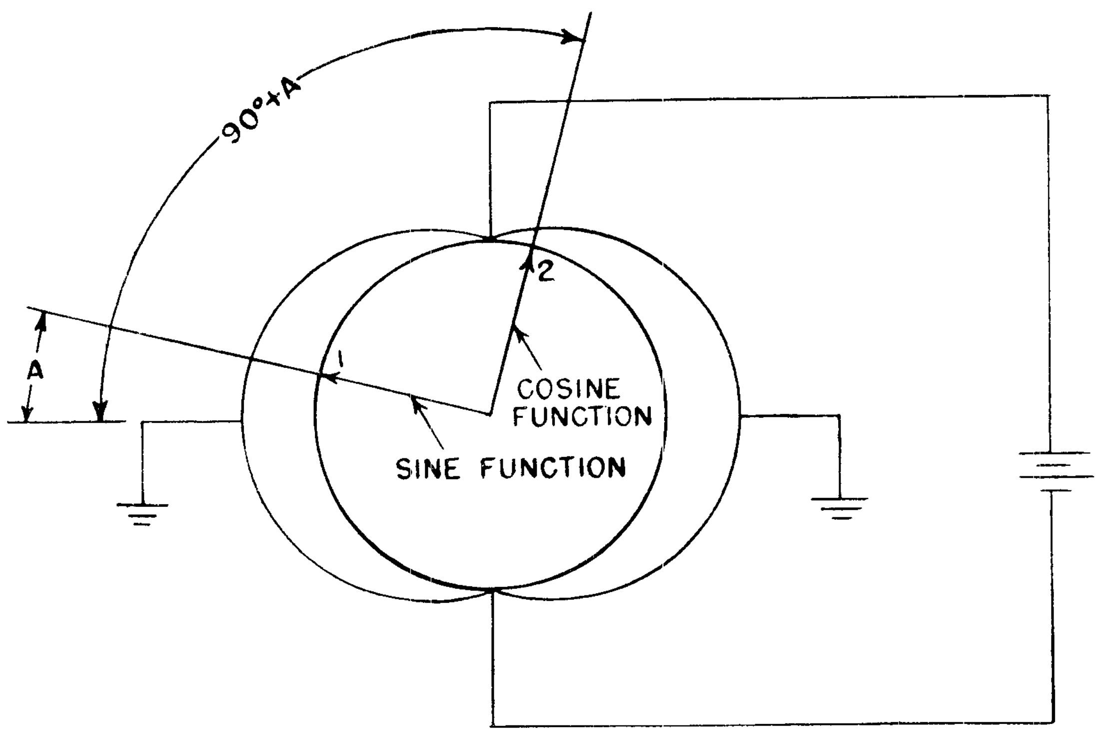


Figure 66. Sine-cosine 360° potentiometer circuit.

89. LOAD RESISTANCE COMPENSATION

Note that in discussing the operation of potentiometers, the voltage tapped by the brush arm has been referred to as a potential. A certain potential exists between the brush arm terminal and the reference terminal before the circuit is closed, or before a load resistance is applied. Figure 64 shows a potentiometer circuit to which a load resistance, R_L, has been connected. The potentiometer resistance, R, is the sum of the two sections, r and r'. However, load resistance R_L connected across section r' will result in a lower resistance value, r'', which can be obtained from the equation $r'' = \frac{r'R_L}{r'+R_L}$. The new value, r'', in series with section r, will cause increased current in the circuit and consequently a lower load voltage applied to R_L from the potentiometer. The difference between the no-load voltage and the load voltage depends upon three factors: the resistance value of the potentiometer, the resistance value of the load, and the position of the brush arm. The error caused by the loading can be compensated for by adjusting the shape of the card after the value of the load resistance is determined. The card is shaped so that the no-load voltage is higher than the desired load voltage by the amount the load voltage would drop if no shaping were introduced.

90. SHAPED POTENTIOMETER CARDS FOR FUNCTION GENERATION

Card shaping is also used to allow the potentiometer to transfer voltage values to the load, which changes according to some desired characteristic other than linear characteristic. Cards so designed are called shaped cards to distinguish them from linear cards used in linear potentiometers. One type of shaped card is the sine card used in sine potentiometers. The output voltage of a sine potentiometer varies according to the sine function as the brush arm travels from one end to the potentiometer card to the other. Another type of shaped card is the cosine card used in cosine potentiometers to provide voltage changes according to a cosine function. The shape of the cosine card is the reverse of that of the sine card. There are potentiometers in the Nike I computer circuits that are designed to provide two voltage outputs simultaneously; one representing the sine function and the other representing the cosine function. The physical appearance of one of these potentiometers with its sine-cosine card is shown in figure 65. The two brush arms, attached to a common shaft, are placed 90° from each other. Also, each arm has its own terminal connected to its respective function-amplifying circuit. Figure 66 is the diagram of a circuit using a 360°, sine-cosine potentiometer. In the figure, the sine-cosine card is bent into a complete circle, which allows 360° rotation of the brush arms to provide function-representative voltages in the four quadrants. The voltage-source terminals

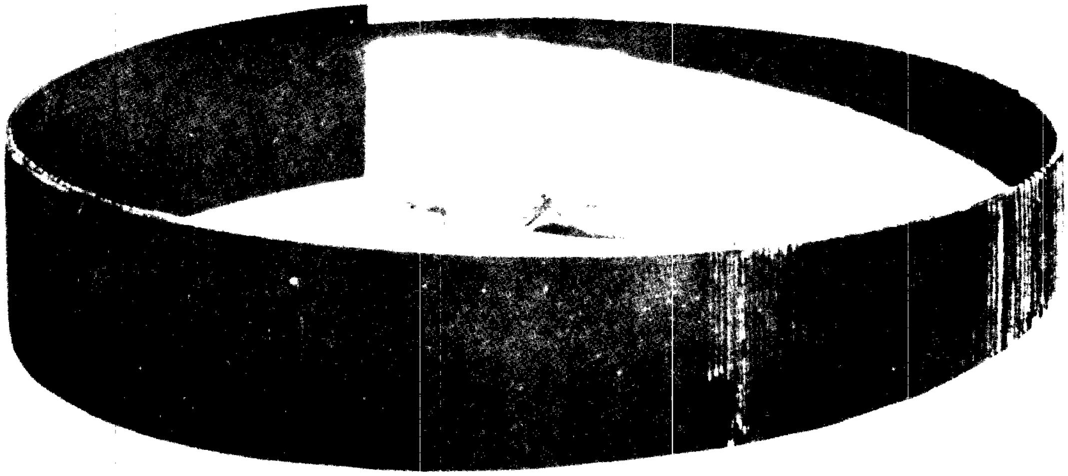


Figure 67. Circular potentiometer card.

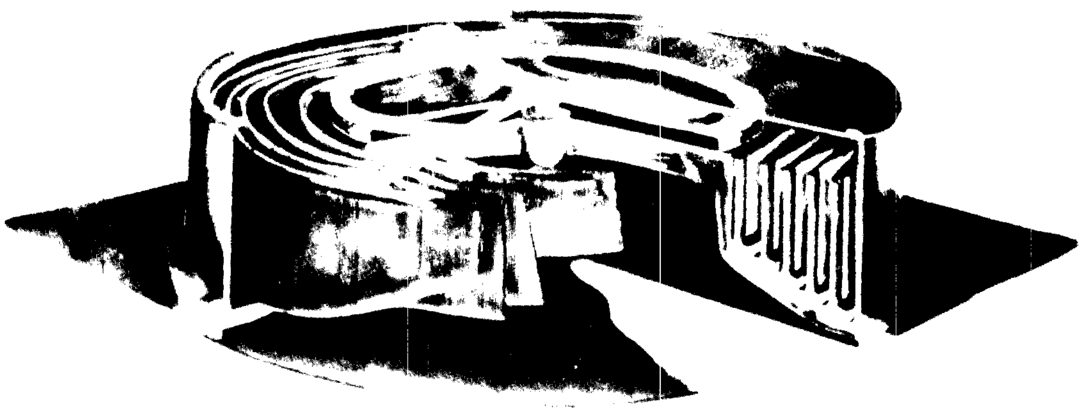


Figure 68. Potentiometers mounted in servo assembly.

are applied to the narrowest points of the card, and ground or reference terminals are connected to the widest points of the card. This arrangement is also used to divide the total applied voltage into two positive sections and two negative sections, corresponding to quadrants in a circle where the function in question is positive or negative. Suppose that brush arm 1 is set at the left ground terminal. The voltage output from this arm is zero, which represents the sine function of zero angular displacement. At the same time, brush arm 2, 90° ahead, produces a maximum positive voltage which represents the cosine function of zero angular displacement. The potentiometer shaft is then turned to angle A. The change involved has caused arm 1 to approach the positive terminal, increasing its output in a sine curve, and has caused arm 2 to approach the ground terminal, decreasing its output in a cosine curve. The same process can be continued around the circle, thus obtaining the sine-cosine functions in the four quadrants in the form of two output voltages. Besides the types of potentiometer cards discussed in the preceeding paragraphs, the Nike I computer requires several other types of potentiometer cards shaped to provide other desired functions.

91. CONSTRUCTION OF FUNCTION GENERATING POTENTIOMETERS

Function generating potentiometer cards consist of a strip of specially compounded hard rubber 0.04-inch thick, and a length of nichrome wire 0.003-inch in diameter, which is wound on the strip. The length and shaping of each card are determined by mathematical computation and trial. One edge of the card is contoured for the desired function generation; the other edge is made straight for a sliding path for the brush arm. The wire is not annealed and has an enamel insulation which is removed from the straight edge of the card to allow contact with the brush arm. Potentiometer cards are machine-wound to attain the required accuracy. After the cards are made, they are bent into a circle or into an arc, depending upon the type of potentiometer. Figure 67 shows the arrangement of a circular card potentiometer, with its brush arm pivoting from the center of the circle. Other types of circular-card potentiometers have several cards in a concentric arrangement. Figure 68 shows this type of potentiometer. In the figure each card has a brush arm, and all the brush arms are attached to a common shaft. The circular cards are held in position by clamping them to a metallic drum called a mounting ring. When the cards are bent, the voltage tapped at every angular position is not absolutely correct. To compensate for this error, the computed length of the card is slightly extended and the card is clamped at regular intervals. The spacing between clamps is figured to distribute any remaining error over the entire length of the card, so that at each clamp position a true voltage value is tapped. The

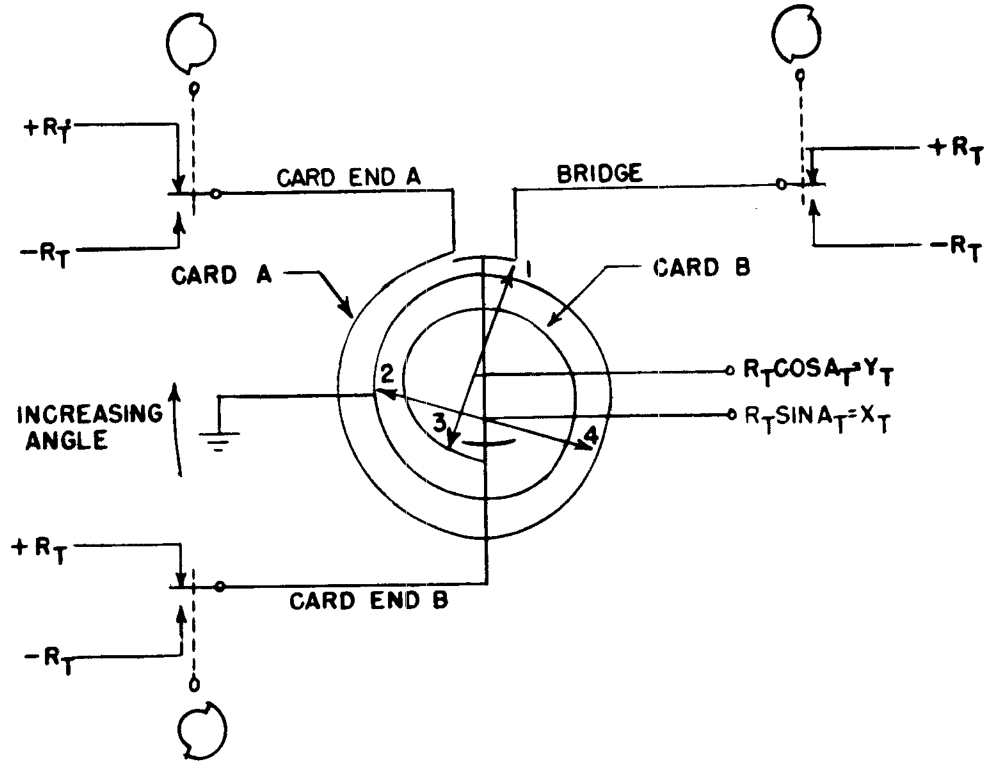


Figure 69. Sine-cosine spiral potentiometer.

arm, therefore, can travel only the 360° angular distance of the circle; in the spiral potentiometer the card is bent into a spiral around the potentiometer shaft. The brush arm therefore can be made to travel a greater angular distance around the potentiometer shaft. To obtain smaller voltage changes within a specified distance, the length of the resistance wire has to be extended. On that basis, a considerable length of resistance wire is wound on the insulating strip to form the potentiometer card. Since the card width is subject to shaping, the length of the resistance wire will determine the length of the card. If the card is bent into a circle, as in conventional potentiometers, the length of the card will determine the dimensions of the circle involved. The diameter of the potentiometer however, will reach a limitation as to permissible over-all size and weight. From the foregoing, it follows that conventional potentiometers are subject to two functional limitations: the traveling angular distance of 360° and the permissible over-all size and weight.

casing containing the potentiometer cards is filled with Bayol-D, a highly refined kerosene, for the dual purpose of insulation and brush arm lubrication.

92. PADDING

The total resistance of a card potentiometer is made up of the resistance of the wire wound on the card, and an external resistance connected between the brush arm and ground, known as padding. For the representative voltage for a given angular displacement of the brush arm to be the same for all potentiometers of the same type, the ratio of resistance included at that brush position to the total potentiometer resistance must be the same. Unavoidable variations in the resistance of wire wound on the card make it impractical to produce cards of the same type having identical resistance value. The resistance of the padding is specially selected to suit the particular card. When a new card is substituted, the padding resistance must be changed to maintain the desired relationship.

93. OPERATION OF POTENTIOMETERS

A potentiometer is operated by rotation of its shaft. The shaft, which is attached to the brush arm, positions the brush arm on the potentiometer card. In the Nike I computer circuits, the card potentiometers are operated in one of two ways: mechanically or manually. A dial and a dial assembly are usually connected to the potentiometer shaft to indicate the position of the brush arm. The primary data potentiometers used to generate functions of azimuth or elevation are mechanically operated. The rotation of their shafts is controlled by the antenna and the necessary coupling is provided by a gear train. Manually operated potentiometers are called handset potentiometers and are used to set data into the computer. The shafts of handset potentiometer are controlled by handwheel drives or by hand knobs. A dial arrangement positioned by the shaft indicates the corresponding function generated.

Section VII. SPIRAL DATA POTENTIOMETERS

94. GENERAL

Spiral data potentiometers are variable voltage dividers whose principle of operation is identical to the conventional circular potentiometers described in section VI. The difference between a conventional potentiometer and a spiral potentiometer is that in the conventional potentiometer, the card is bent into an arc or circle whose center is the potentiometer shaft. The brush

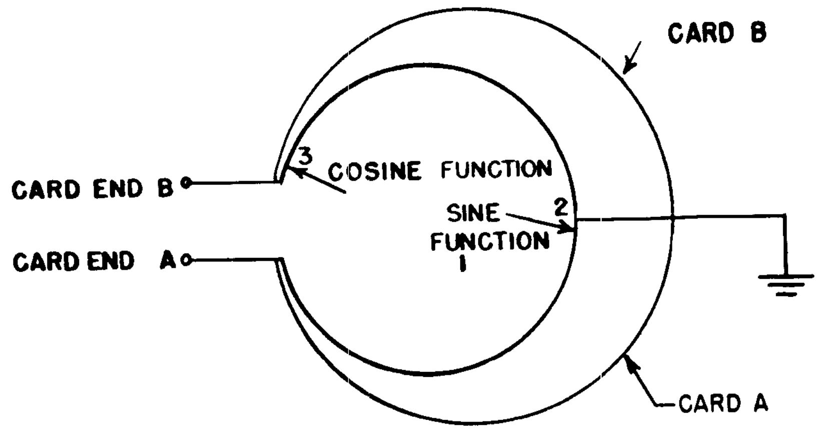


Figure 70. Azimuth or elevation potentiometer cards

When a voltage, ±E, proportional to the slant range, $\pm D_T$, at a definite scale factor, is applied to the elevation sine-cosine potentiometer and the brushes are positioned by the elevation angle, E_T, the output voltage from the cosine brush represents the ground range, R_T, and is equal to $D_T \cos E_T$. The output voltage from the sine brush represents the height, H_T, and is equal to $D_T \sin E_T$. The azimuth potentiometer in the target tracking radar contains a sine-cosine card because it resolves the ground range of the target, R_T, and the azimuth angle of the target, A_T, into their rectangular coordinate components the east-west distance, X_T, and the north-south distance, Y_T. When a voltage, E, proportional to the ground range, R_T, at a definite scale factor, is applied to the azimuth sine-cosine potentiometer and the output brushes are positioned by the azimuth angle, A_T, the output voltage from the sine brush represents the east-west distance, X_T, and is equal to $R_T \sin A_T$. The output voltage from the cosine brush (No. 3) represents the north-south distance, Y_T, and is equal to $R_T \cos A_T$. Pages 43 and 45 of 2y show the mechanical schematics of the azimuth and elevation data units. The potentiometer drive shaft in either unit is geared to the antenna drive gear at a ratio of 5 to 1. The sine-cosine spiral card is mounted on a flat surface. The potentiometer shaft drives four brushes. These brushes are displaced by 90°. Only two brushes traverse the spiral card at one time, giving a sine and cosine function at the output. The potentiometer brushes are driven by the potentiometer drive shaft in such a way that each brush travels the entire length of the associated card section (card A or card B), while the antenna rotates through an angle of 1,600 angular mils (90°). The same description of target coordinate conversion can be applied to missile coordinate conversion. In that case, the coordinate data is identified with the subscript letter M.

95. CONSTRUCTION

Spiral potentiometers are designed to overcome the limitation of conventional circular potentiometers. The spiral potentiometer card has two sections, shown in figure 69 as card A and card B. For simplicity, the spiral card is shown with a circular form in the figure. The potentiometer shaft has four brush arms attached to it. Brush arms 2 and 3 are placed in quadrature (at 90 electrical degrees from each other) so that one provides a cosine function, while the other provides a sine function. Brush arms 1 and 4 are also placed in quadrature, to provide the same functions respectively. One pair of brush arms (2 and 3) rides the length of the spiral card, while the other pair (1 and 4) is disconnected from the card. When the first pair completes its travel from one end of the spiral card to the other, it is disconnected from the card. The second pair is automatically connected to continue providing the functions of the first pair. The connecting and disconnecting operations are made by a cam mechanism attached to the potentiometer shaft. This mechanism is identified by the bridge terminal in the figure. Besides the bridge cam, there are two other cam mechanisms attached to the potentiometer shaft. The function of these cams is to provide polarity reversal necessary for quadrant switching.

96. COORDINATE CONVERSION WITH SPIRAL POTENTIOMETERS

In the Nike I system, the spherical coordinate information delivered to the computer circuits by the target or the missile radars is converted into rectangular coordinate information by spiral potentiometers. The target range unit assembly supplies the target slant range, D_T. The target elevation data unit supplies the target angular height, E_T. The target azimuth data unit supplies the target azimuth angle, A_T. The spiral potentiometers convert these mechanical analogs into d-c voltages that represent the polar coordinate of horizontal ground range, R_T, and the rectangular coordinates of the target. The output voltages from the spiral data potentiometers represent the solution to the following trigonometric equations:

$$R_T = D_T \cos E_T, \tag{11}$$

$$H_T = D_T \sin E_T, \tag{12}$$

$$X_T = R_T \sin A_T, \tag{13}$$

$$Y_T = R_T \cos A_T. \tag{14}$$

at J3-5 through 1-1/4 turns to the ground connection at J2-C. Brushes 1 and 3 are connected to a lead which extends to the right to J2-B, with brush 3 shown making contact with card B. Brush 1 is shown off the card. Brushes 2 and 4 are connected to lead which extends to the left from J2-H. Brush 2 is shown in contact with card A near the ground point, and brush 4 is shown off the card. The potentiometer is geared to the antenna at a 5 to 1 ratio. This means that 1,600 mils of antenna rotation is equivalent to 1-1/4 revolutions of the brushes. Suppose the potentiometer is being used to convert missile coordinates. The input quantities are plus and minus R_M and the output quantities are X_M and Y_M. Suppose the MTR antenna is positioned at 0 mils azimuth. The dial on the azimuth data converter should read 0 mils. From the notes on the schematic, the following information can be obtained for this condition: switches S1 and S2 are operated, switches S3 and S4 are released, and switch S5 is operated. Therefore, the quantity R_M is applied to card A, and the quantity $-R_M$ is applied to card B. The quantity R_M is applied to the bridge. Brush 2 will be at ground potential. Therefore, the voltage at J2-H will be zero and the quantity X_M is zero. Brush 3 will be on the bridge, to which is applied the quantity R_M. Therefore, the quantity Y_M is equal to R_M. Table I shows the conditions existing in the azimuth data converter for an azimuth angle in any quadrant. Points to keep in mind are that the brushes always retain the same function throughout their angular travel. Cards A and B, however, alternate functions as the azimuth shifts from one quadrant to the next succeeding quadrant.

101. ELEVATION POTENTIOMETER QUADRANT SWITCHING

Quadrant switching in elevation is done in the same manner as quadrant switching in azimuth, and the same description applies. In a practical sense, quadrant switching in elevation will not occur during an engagement because the antenna excursion will be limited to an upper value of between 1,150 and 1,590 mils and a lower value of from 30 to 50 mils. The inputs to the elevation data potentiometer are the plus and minus quantities representing slant range.

102. OPERATION

Since data potentiometers are located on the antenna assembly and are remotely located from the computer, the ground part of the potentiometer is lifted off true ground by the line drop in the ground lead of the data cable. A voltage drop in the ground lead cannot be tolerated. Consequently, there must be no current in the ground lead. To eliminate the voltage drop in the ground lead, dummy loads consisting of R3, R4, R5, and R6 are provided in

97. RANGE DATA POTENTIOMETER

The range data potentiometer produces a voltage that is porportional to the slant range of the target, D_T, when a scale factor of 1 millivolt per yard is used. The range data potentiometer for each tracking radar is located in a range unit assembly. The range potentiometer is a 2-1/2-turn spiral card, 90 inches long. The brush speed of the card is 2.5 to 1 when referred to the basic range motor speed. In moving from zero range to the maximum range of 100,000 yards, the brush arm will make 2-11/32 revolutions.

98. AZIMUTH AND ELEVATION POTENTIOMETERS

The azimuth and elevation potentiometer cards are identical spiral cards (fig 70). Each card has two sine-cosine shaped electrical quadrants (180°). That is, the card A and card B sections are sine cards (or cosine cards), physically joined at the wide end to form one sine-cosine spiral card. The spiral card is grounded at the widest section and the input voltages are applied at the narrow ends of card sections A and B, and at the bridge. The input voltages can be positive or negative, depending upon the position of the cams. The cams are driven by the potentiometer drive shaft, which is geared to the antenna. The azimuth and elevation data potentiometers have 2-1/2 spiral revolutions and are 90 inches long. The card has a maximum width of 2 inches and a minimum width of 0.18 inch. The elevation potentiometer in the target-tracking radar contains a sine-cosine card because it is necessary to convert the spherical coordinates D_T and E_T into the quantities R_T and H_T.

Section VIII. QUADRANT SWITCHING

99. GENERAL

Quadrant switching is the polarity reversal of the d-c voltages applied to a spiral potentiometer. The spiral potentiometer card is shaped to generate sine or cosine functions only within 180°, or 3,200 mils, which is the equivalent. Since the potentiometer shaft is continuously driven clockwise or counterclockwise by the radar antenna, quadrant switching enables the spiral potentiometer to continuously provide the correct sign for the azimuth or elevation functions generated.

100. AZIMUTH POTENTIOMETER QUADRANT SWITCHING (TM 9-5000-26)

On page 42, card A extends from the connection at J3-8 through 1-1/4 turns to the ground connection at J2-C. Card B extends from the connection

the azimuth and elevation data units. They are switched between the plus and minus inputs to keep the currents equal, so that no potentiometer current flows in the computer ground lead. Microswitches S3 and S1 are used for this purpose.

103. POTENTIOMETER FIELD PRACTICES

Nike battery repairmen should not attempt potentiometer repair. The potentiometer is a precision device and requires extreme care by experienced ordnance men for maintenance and repairs. Care must be exercised not to expose parts to dust, lint, chips, or corrosive contamination. Potentiometers should be exposed only in a dry, dust free atmosphere. Every precaution should be taken to keep contaminants from the brush contact surface. When it is necessary to disconnect wires, be certain that the wires are properly identified by tags. When it is necessary to remove a lower housing or oil pan from a servo unit for repair or adjustment, the potentiometer and parts inclosed within the oil pan should be thoroughly washed with potentiometer oil. This is done by attaching the oil pan to the servo unit and filling it with clean oil to the indicating mark on the oil gage. When the potentiometer and other parts have been thoroughly washed in this manner, drain the oil. After the oil has been completely drained, the oil pan should be removed, and the inside of the oil pan wiped with a dry, lint-free cloth to remove any sediments which may have been collected. The oil pan of a potentiometer is provided with an oil sight window, a combined stop-cock and lubrication fitting for filling and draining purposes, and a vent cock. The oil from the potentiometer should be removed if the unit is to be transported, stored, or subjected to excessive handling. If the potentiometer is in use, be sure that the oil level is kept at the level indicated by the gage. All brushes should be checked for contact pressure. If the pressure is not within requirements, it must be adjusted. The contact pressure is adjusted to assure a reliable contact between the potentiometer resistance wire and the brush. There are drum index marks on the potentiometers, and the brushes are adjusted so they are in line with their drum index marks. The dials are rotated on shafts to their correct positions and are secured there by tightening the retaining screws. When checking the resistance of the potentiometer card, do not exceed the current rating of the card.

Section IX. COMPUTER SERVOS

104. GENERAL

In the Nike I computer, physical quantities such as distances, velocities, and angles are represented in one of two ways: by a d-c voltage proportional

Quad-rant	Azimuth in mils	Polarity of R_M applied to: Card A	Card B	Bridge	Brush position with respect to cards: 1 Cos	2 Sin	3 Cos	4 Sin	Card function: A	B	Switch condition: S1 S2	S3 S4	S5
I	0	+	−	+	On bridge	GD	On bridge	Off	Sin	Not used	Opr	Rel	Opr
I	0-5	+	−	+	On bridge	On A	On bridge	Off	Sin	Not used	Opr	Rel	Opr
I	5	+	+	+	On bridge	On A	On bridge	Off	Sin	Cos	Opr	Opr	Opr
I	5-1595	+	+	+	Off	On A	On B	Off	Sin	Cos	Opr	Opr	Opr
I	1595	−	+	+	Off	On bridge	On B	On bridge	Not used	Cos	Rel	Opr	Opr
I	1,595-1,600	−	+	+	Off	On bridge	On B	On bridge	Not used	Cos	Rel	Opr	Opr
II	1,600	−	+	+	Off	On bridge	GD	On bridge	Not used	Cos	Rel	Opr	Opr
II	1,600-2,400	−	+	+	Off	Off	On A	On B	Cos	Sin	Rel	Opr	Opr
II	2,400	−	+	−	Off	Off	On A	On B	Cos	Sin	Rel	Opr	Rel
II	2,400-3,200	−	+	−	Off	Off	On A	On B	Cos	Sin	Rel	Opr	Rel
III	3,200	−	+	−	On bridge	Off	On bridge	GD	Not used	Sin	Rel	Opr	Rel
III	3,200-3,205	−	−	−	On bridge	Off	On bridge	On A	Sin	Not used	Rel	Opr	Rel
III	3,205	−	−	−	On bridge	Off	On bridge	On A	Sin	Not used	Rel	Rel	Rel
III	3,205-4,795	−	−	−	On B	Off	Off	On A	Sin	Cos	Rel	Rel	Rel
III	4,795	+	−	−	On B	On bridge	Off	On bridge	Not used	Cos	Opr	Rel	Rel
III	4,795-4,800	+	−	−	On B	On bridge	Off	On bridge	Not used	Cos	Opr	Rel	Rel
IV	4,800	+	−	−	GD	On bridge	Off	On bridge	Not used	Cos	Opr	Rel	Rel
IV	4,800-5,600	+	−	−	On A	On B	Off	Off	Cos	Sin	Opr	Rel	Rel
IV	5,600	+	−	+	On A	On B	Off	Off	Cos	Sin	Opr	Rel	Opr
IV	5,600-0	+	−	+	On A	On B	Off	Off	Cos	Sin	Opr	Rel	Opr

Table I. Quadrant switching operation of missile azimuth data converter.

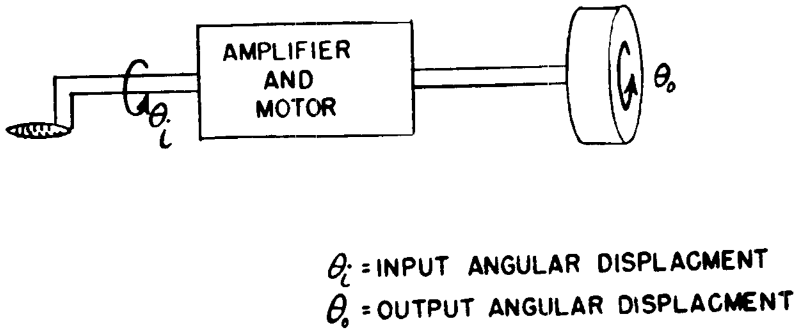


Figure 71. Open-loop control system.

106. OPEN-LOOP CONTROL SYSTEM (fig 71)

Keeping in mind that the whole purpose of a servo is to control power and make the output of the system (controlled variable) follow or do what the reference input commands, consider the components necessary to do this. Consider a small handwheel with which it is desired to position a large, heavy disk, remotely located from the handwheel, so that one revolution of the reference input (the handwheel) results in one revolution of the controlled variable (the disk). The low-power level input can be amplified by gears and a motor to cause the rotation of the disk. However, after the disk has rotated in response to the reference input, it is not certain that the disk has completed one revolution for one revolution of the handwheel. This is because the actual operating characteristics of the motor and amplifier may change because of wear and other factors. Furthermore, from a knowledge of the value of the controlled variable alone, there is no way of determining that there is a difference between the reference input and the controlled variable. It is impossible in an open-loop control system to distinguish between a change in the reference input and a change in the amplifying characteristics of the motor amplifier combination as far as its effect upon the load is concerned. Therefore, close tolerances are needed for high performance in an open-loop control system, hence the use of an open-loop control system in many applications will be uneconomical.

107. USE OF FEEDBACK

To improve this system, it can be modified by a feedback loop or circuit (fig 72) which detects and sends information back (feedback function of the controlled variable) to a device (comparator) which will compare the feedback with the reference input. If there is a discrepancy between the input and

to the physical quantity, or by a shaft position proportional to the physical quantity. In either case, the representative voltage or shaft position (which is the analog) is related to the physical quantity by a scale factor. Since the Nike I computer uses both methods of representation, it requires frequent conversion from one representation of a quantity to the other. The device used for converting a shaft position (mechanical analog) into a voltage (electrical analog) is a potentiometer described in previous paragraphs. The opposite conversion, from a voltage to a shaft position, is done by a servo. The basic principles of servo operation are discussed in this section.

105. BASIC PRINCIPLES AND DEFINITIONS

a. Servos permit a low-power signal to control a large output or load, the load following the input faithfully. In many instances, the load is remotely located from the low-level power input source. A servo system is a combination of control systems of different types. Types of control systems are defined as follows:

(1) Open-loop (cycle). A system in which the control is independent of the result.

(2) Closed-loop (cycle). A system in which the control operation is a function of the result.

(3) Discontinuous. The flow of energy in the system is either zero or some predetermined value.

(4) Continuous. The rate of flow of energy in the system can be adjusted between certain limits in the system.

b. For all applications in the computer, a servo will be considered as embodying the features of a closed-loop, continuous system, and it will be defined as: a feedback control system in which the difference between the reference input and some function of the controlled variable is used to supply an actuating error signal to the control elements and the controlled system. The amplified actuating error signal endeavors to reduce the difference between reference input and the controlled variable to zero. It has been stated that the control is continuous. Through continued use of the actuating error, such a feedback control system can be made accurate without requiring high accuracy or constant performance characteristics for all the control elements.

b. Comparator. The comparator is a mechanical, electrical, or electromechanical device that gives an indication of the amount and direction (polarity) of the error, or the difference between the reference input and the controlled quantity (output).

c. Controller. The controller is a power amplifier and servomotor combination which converts and amplifies the actuating error into a high-powered signal which drives or positions the output shaft.

d. Controlled variable. This is the load or driven mechanism which is positioned to correspond faithfully to a given input. Its motion is generally an angular displacement of a shaft.

e. Feedback element. The feedback element is an electromechanical device for converting the output variable to a quantity that is a function of the controlled variable, and is of dimensions suitable for comparison with the reference input. Generally, the feedback element converts mechanical motion to an electrical signal.

f. Feedback. Feedback is the quantity that represents the controlled variable and is brought into the comparator for comparison with the reference input. It must always be of the opposite sense with respect to the reference input, and is called negative or degenerative for this reason.

109. REFERENCE INPUT

The primary consideration concerning the reference input is the manner in which the magnitude of the input varies with time. Using this as a means of classification, there are three types of inputs. At any one instant of time, the input may be a combination of the two functions, step or ramp. The sine function is important, because any other function may be considered a combination of sine functions, each with a different frequency.

a. Step function. When the reference input is suddenly applied at one instant of time and then maintained constant, it is said to be a step function (fig 73).

b. Ramp function. This function is one in which the input is initially zero until some instant at which the input begins to change at a constant rate with respect to time. Since the graph of this function looks like a ramp, it is called a ramp function. A constant velocity input is an example of a ramp function. A ramp function is illustrated in figure 74.

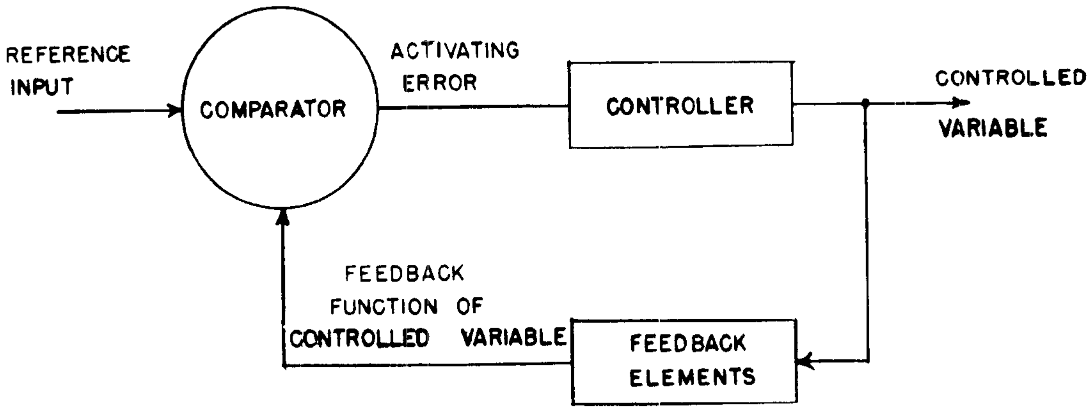


Figure 72. Basic servo, block diagram.

output positions, an actuating error signal proportional to their difference continues to keep the system in motion until the position of the output shaft corresponds to the position commanded by the reference input. When this condition exists, there will be no difference between the feedback and the reference input and the resulting actuating error is zero. For the closed-loop control system there is less need for maintained the amplifying characteristics of the controller at close tolerances, if the gain is high. In the open-loop control system, a reduction of the amplifying characteristics of the motor and amplifier to a value nine-tenths of the nominal gain will result in an output shaft motion nine-tenths of the desired motion. In the closed-loop control system, however, a reduction in amplifying characteristics of the controller by one-tenth will result in a reduction of the output shaft motion equal to $\left(\frac{1}{1 + G}\right)(0.1)$ times the amount of desired motion. Thus, if the gain is high, a change in the operating chacteristics of any one physical element in the system will not introduce appreciable inaccuracies in the desired position.

108. COMPONENTS

A simple servo requires six components which are basic to the system.

a. Reference input. A reference input is the controlling quantity the servo must faithfully reproduce at its output, either exactly, or in the form of an analog which is exactly proportional to the input. The reference input may be either mechanical or electrical.

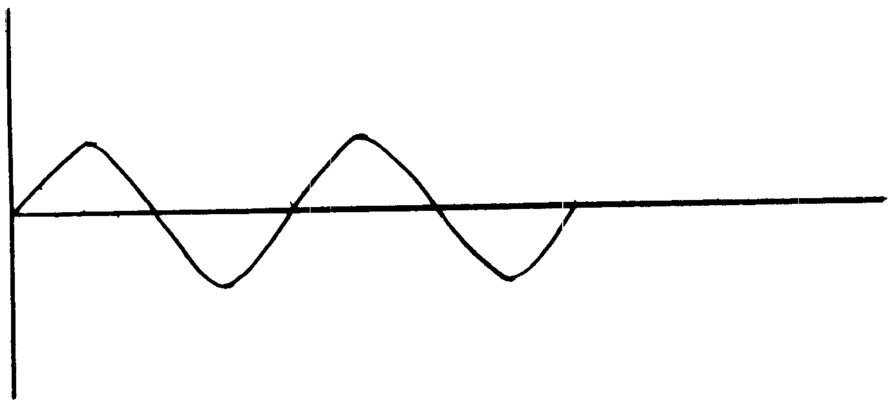


Figure 75. Sine function.

motion will cease. This is true only for position type servos. To keep the output shaft continuously in motion there must be an actuating error. The servo strives continuously to reduce the actuating error to zero and in so doing drives the output shaft so that the inaccuracy between the reference input and the desired controlled quantity is, for practical purposes, negligible, as far as the load is concerned.

111. CONTROLLER

All servos in the Nike I system use a-c motors as servomotors, and in most instances the actuating error is a d-c voltage. For the controller to convert and amplify the actuating error into a suitable high-power driving signal, two components are included. These are a modulator and a low-power amplifier which have been discussed in sections II and III of this chapter.

112. CONTROLLED VARIABLE

In all cases in the computer, the controlled variable is the position of the servomotor shaft analogous to the quantity being computed. Through suitable gearing, loads are attached to the output shaft. These loads may convert the shaft position to electrical quantities for some applications.

113. STABILITY AND RESPONSE

Stability and response are two of the most important terms which may arise in servo analysis and discussion. The more stable a servo is, the less will be

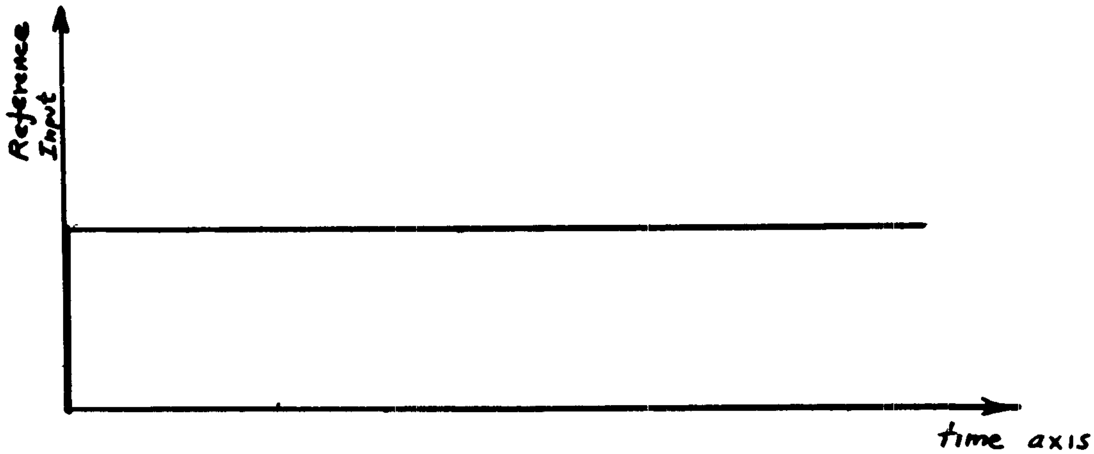


Figure 73. Step function.

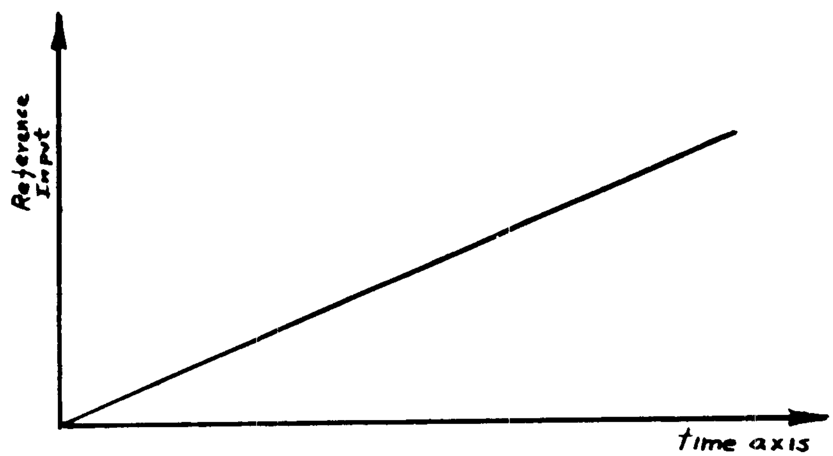


Figure 74. Ramp function.

c. Sine function. This input, probably the most important in the analysis of servos, is one in which the input alternates first in one direction and then in the other with respect to a reference level, usually zero. The graph of this function with respect to time is a sine wave (fig 75).

110. ACTUATING ERROR

In a practical sense, most servos in the Nike I system are continuously in motion as the computer solves the problem. Previous discussion has brought out the fact that when the actuating error is zero, the output shaft

its tendency to oscillate or hunt about the desired output position, but, on the other hand, the slower its response will be. .High stability is obtained only by sacrificing speed of response. Rapid response is obtained only at the expense of potential instability. Therefore, in a well-designed and properly maintained system, a compromise is obtained and kept between the two considerations. Instability arises initially because the motor and load have inertia, and the elements of the controller, as well as the load, have elasticity. Inertia is analogous to inductance and elasticity is analogous to capacitance. Thus, in effect, the servo is a tremendous electromechanical tank circuit. If this tank circuit is shocked into oscillation, the output member will hunt or oscillate until the friction between the moving parts (viscous friction) damps it out. For accurate reproduction of reference inputs, a high-gain controller is necessary. However, if the gain is too high, instability will result. High gain is obtained only at the expense of considerable phase shift. The basic principle in the use of feedback is that the feedback be negative (degenerative). If, however, the phase shift through the controller with respect to the reference input is 90° greater than the usual 180° needed to obtain negative feedback, then a component of positive (regenerative) feedback will exist, which will add to the reference input and tend to sustain oscillations. If this condition is allowed to persist, not only do inaccuracies result, but the component parts may be damaged. To obtain stability, additional damping is added. In the Nike I system, this damping is obtained through speed feedback damping from generators within each servomotor assembly. As an aid in compensating for excessive phase shift which would produce high instability, compensating networks are used. These networks are usually R-C electrical networks, and in some cases bridged-T networks.

114. AUXILIARY FEEDBACK LOOPS

Speed feedback damping and phase compensation are obtained through the auxiliary feedback loops. The feedback is taken from the output shaft. It is not generally applied to the comparator, but rather to other components in the servo, usually the controller.

115. TYPICAL APPLICATIONS

A typical application of a servo is one in which a DC amplifier, used as a summing amplifier, is the comparator. This application can best be understood by first examining the operation of the DC amplifier (fig 76). A DC amplifier, when used as a summing amplifier, yields an output voltage equal to the algebraic sum of its inputs. If the positive voltage is greater,

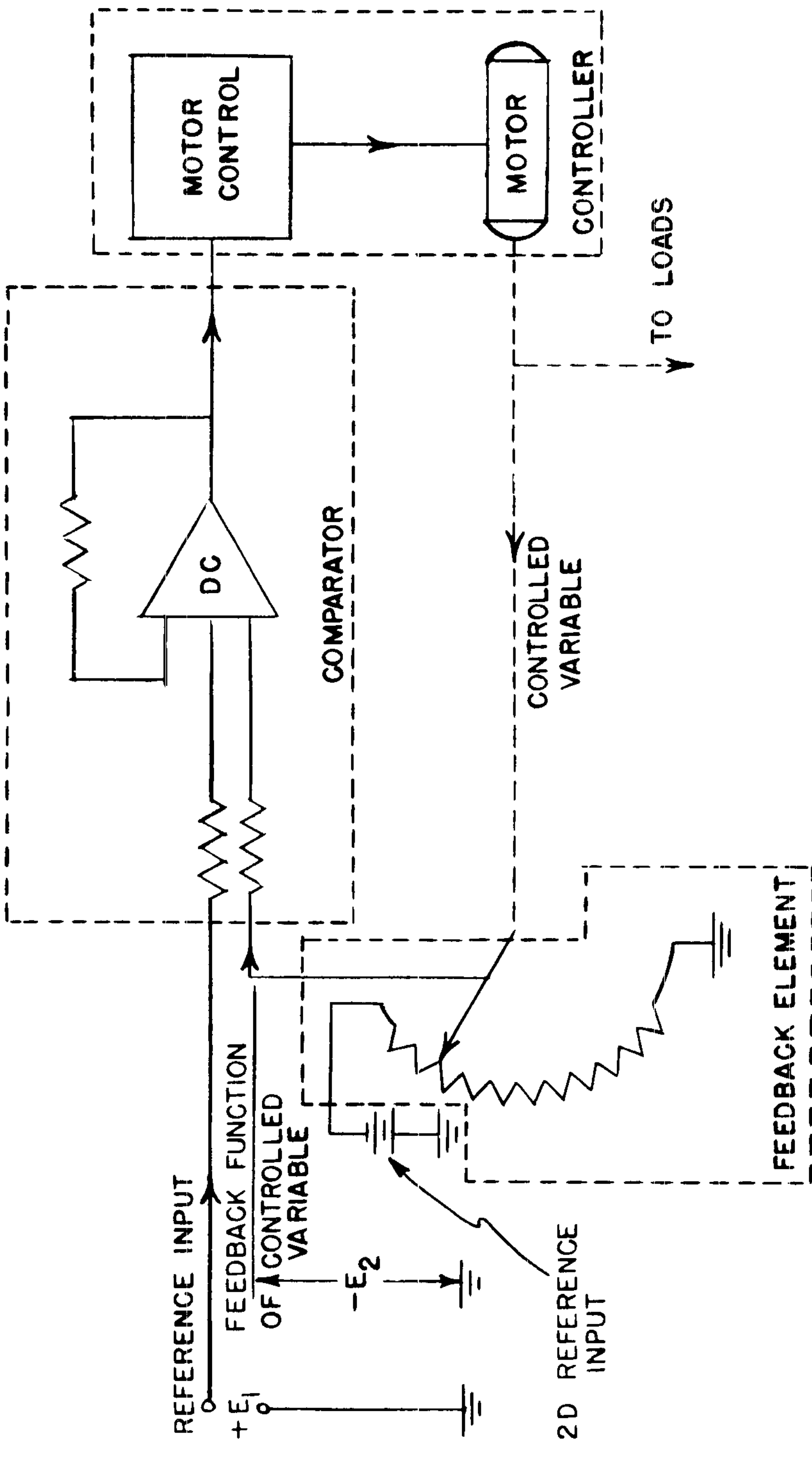


Figure 76. Simple computer servo.

CHAPTER 6

POWER DISTRIBUTION AND VOLTAGE REGULATORS

Section I. A-C POWER DISTRIBUTION

116. GENERAL

Table II indicates the complexity of the problem which the maintenance man faces in tracing the alternating current distribution throughout the computer. However, by careful use of the references indicated and after enough practical experience, the student will soon be able to trace the a-c distribution with ease.

Table II. Index for a-c power distribution.

VOLUME	PAGE	SUBJECT MATTER
2y	158, 159	Power cabinet distribution.
2y	160	6.3 a-c distribution.
2y	161	A-C distribution.
2y	163, 164	Distribution of power from bus bars.
2y	165	Power and miscellaneous connections.

117. POWER CABINET DISTRIBUTION (pages 158 and 159 of TM 9-5000-26)

These pages indicate the various switches, transformers, rectifiers, regulators, and other circuits in the computer power cabinet. On the far left of page 158 (A1, B1, C1, and D1) are shown the main power switch, radar power switch, and computer power switch through which phase A, phase B, and phase C enter the power cabinet. The MAIN POWER and ACQ POWER switches are in the acquisition power cabinet, and the COMPUTER POWER switch is on the front of the power cabinet on the power control panel. All three phases are fused and have burnout indicating lights paralleling the fuses. Phase C to neutral passes through the 120-volt regulator (C2), and, with the two unregulated phases is used for the various rectifiers, regulators, and filament transformers. Interlocks (A7) prevent operation if any of the cabinet doors are open. Interlock

the output of the amplifier is a negative voltage; if the negative voltage is greater, the output is positive. The output of the amplifier is zero when the magnitudes of the two input voltages are equal. If one of the input voltages to the DC amplifier is furnished by a potentiometer whose brush is positioned by a reversible motor controlled by the output of the DC amplifier, the output voltage of the amplifier is automatically maintained at zero. When voltage E1 is greater than E2, the DC amplifier output is negative and causes the motor to turn the potentiometer brush in a direction which increases E2. When E2 is increased until it equals E1, there is zero voltage output from the amplifier and the motor stops. If E1 is less than E2, there is a positive output from the DC amplifier which causes the motor to turn in the opposite direction until E2 is again equal to E1. No matter how E1 varies (within the range of potentiometer output) E2 will always be maintained at a value equal to E1. This is a servo system in the simplest form. The servo is an electromechanical balance which equates two quantities. In the example given, it solves the equation:

$$E1 - E2 = 0; \tag{15}$$

or

$$E1 = E2. \tag{16}$$

The position of the potentiometer brush is a mechanical representation of the value of E1. If several input voltages are applied to the amplifier, the position of the potentiometer brush mechanically represents the algebraic sum of these voltages. Thus, the servo systems transform electrical data (a voltage) into mechanical data (angular position of a shaft).

This can be seen by glancing to the right of the plug, where a typical modulator is displayed. In the block labeled typical modulator P2, is a pin labeled P2-14. This pin 14 brings 6.3 volts into the modulator. Jack J242-14 on page 160 has 6.3 volts coming into it, showing that the X_{SL} and X_{SR} modulator chassis is the correct termination for J242-14. Heavy black terminations on page 160, preceded by an E, indicate that the termination is a bus bar. For example, at C5 is E256, which carries 6.3 (-200) volts. To find where this voltage goes, turn to page 163. In the upper left corner of these blocks is a bus bar number. On each frame the bus bars are numbered in sequence from left to right. On the left of page 163 at the top is a label, left frame, and the blocks from left to right are E250, E251, E252, etc. Bus bar connection E256, at coordinates C2, is the bus bar being traced. The 6.3-(-200-) volt potential goes to many points. For example, from pin 2 to E256, the voltage goes to J83-14. On page 165 at A4 is the target ~~and~~ ground speed amplifier input network. Plug P1-14 is ~~labeled~~ J83 and has 6.3 (-200) volts coming into it. This is the correct termination point.

120. DISTRIBUTION OF POWER FROM BUS BARS (pages 163 and 164 of TM 9-5000-26)

These pages have been used to trace a voltage from page 160 to page 165 in paragraph 119. All of the bus bars in the computer are shown here. The bus bars are on the left swinging frame, the right swinging frame, and rear frame of the amplifier cabinets. At the top of each box is the voltage which is present on the bus bar. In the upper left hand corner of the box is the number of the bus bar with the terminal numbers of the bar below it. As an example, in A1 the bus bar has +250 volts applied, the number of the bar is E250, and on it are 10 termination points. A lead from terminal 2 goes to J83-6. The student can find J83-6 on page 165 A4. In the upper right hand corner of each box is the label NOTE, and at various terminals, under NOTE, numbers from 1A to 1V can be seen. As an example, at A9 is the 250-volt bus bar, E760. Terminal 1 has note 1U, indicating an additional termination. At coordinate A5, note 1U shows that the additional termination is at J95.

121. POWER AND MISCELLANEOUS CONNECTIONS TO COMPONENTS (page 165 of TM 9-5000-26)

This page shows the relay panels, input networks, and components of the computer. The pin numbers for plug P1 are shown with the inputs labeled on the panels. At A5 is a block showing various jacks and to the right of this block is a typical DC amplifier. This method is used to conserve space, since all the working voltages into the amplifiers are the same, although the input

override switches are provided to allow normal operation with an open door. The outputs of the rectifiers are shown at A10, B10, C10, and D10. The outputs are fused; most of them go to regulators, and from there to various parts of the computer. In A13, B13, C13, and D13, the numbers of the sheets and coordinates to which the repairman should turn to continue tracing the voltages are indicated. On various parts of the page are symbols indicating meter connections. The connections through the voltage check switch and meter are shown at coordinates 15 and 16. On page 166 the various types of ground in the computer are shown.

118. A-C DISTRIBUTION (page 161 of TM 9-5000-26)

This page shows motor excitation (mtr X), tachometer excitation (tach X), and plotting board voltage distribution. At C7 and C8 is a diagram indicating the various voltages and the typical motor-tach connections. On the far left of page 161, coordinates A1, B1, and C1, the sheets showing where the voltages come from are indicated. As an example, phase C mtr X comes from the power cabinet, terminal 837, which is shown as leaving page 158 at coordinates D7. This a-c voltage is phase C and is termed mtr X because it is used in the motors of the servo systems as excitation. Similarly, phase AB, tach X is the alternating current used in the generator of the servo systems as excitation. Phase C mtr X goes through the computer condition switch, S1 (A2), and is applied to several servos. Other phase C mtr X voltages go directly to servomotors, bypassing S1. Tach X enters page 161 at A4 from page 158 D7 and is distributed to modulators and generators as indicated. Voltage connections for the plotting board lights are shown at A7 and A8.

119. 6.3-VOLT A-C DISTRIBUTION (page 160 of TM 9-5000-26)

Junctions bus bars, and jacks on this page indicate where 6.3-volt a-c is connected. This page shows the most convenient points for testing voltage flow between components. The combining of -200-volt A and -200-volt B with 6.3 volts is shown at C4 and at C7. The connections to the lights used on the servos to illuminate the dials are shown at coordinate 4. At coordinates D2 is a block of numbers. The J preceding each number, for example, J242-14, indicates that the 6.3-volt potential appears at this jack. On page 165 are the plugs which are inserted into the jacks. These plugs are on the various chassis and panels in the computer cabinets. To find the plug which is inserted into J242, the student should turn to page 165. At D6, in the left rear frame, is designation J242. The plug is on the X_{SL} and X_{SR} modulator.

Table III. Index of d-c power distribution

VOLUME	PAGE	SUBJECT MATTER
2y	158, 159	Power cabinet distribution.
2y	160	6.3-volt a-c distribution (and -200 volts A and B).
2y	162	D-C distribution.
2y	163, 164	Distribution of power from bus bar.
2y	165	Power and miscellaneous connection to components.

124. POWER CABINET DISTRIBUTION (pages 158 and 159 of TM 9-5000-26)

Phases A, B, and C enter the rectifiers at coordinates A4, B4, and C4. The outputs of the rectifiers can be seen at coordinates B10, C10, and D10. These d-c voltages are fuzed and all are sent to regulators except -320A, +320B, -28, and +270 volts. The jacks and sheets to which these voltages can be traced are shown at coordinates A13, B13, C13, and D13. The meter at coordinates 15 and 16 is located on the power control panel and indicates the presence and the magnitude of the various voltages.

125. -200 VOLTS A AND B

In TM 9-5000-26, page 160, at coordinates C1 are shown the terminals at which -200-volt A and -200-volt B enter the amplifier cabinet. Minus 200-volt A is mixed with 6.3 volts (C4) on bus bars E256 and E257. Minus 200-volt B is mixed with 6.3 volts (C6) on bus bars E556 and E557. These bus bars are shown on page 163.

126. DISTRIBUTION OF POWER FROM BUS BARS (pages 163 and 164 of TM 9-5000-26)

These pages were discussed in paragraph 120. Both d-c and a-c bus bars are shown. The magnitude and polarity of the d-c voltages are shown above the bus bars. The terminal number of the bus bar is in the upper left corner of each box. At coordinates A1, for example, is the +250-volt bus bar, E250. The terminals on the bus bar are in the left hand column and the points to

jacks are different. As an example, on the left frame, left side is a plug for jack J5. The amplifiers that plug into J5 are the $-D_M$ and $+H_M$ amplifiers. In the triangle representing a DC amplifier are the pin numbers of the plug. Plug P1-2 receives -320 volts from J5. Another example: at A7 is a typical relay amplifier. If the relay amplifier the maintenance man is examining is the CTA amplifier, then J2 is the jack which is inserted into the chassis.

122. TRACING AN A-C TROUBLE IN THE COMPUTER (TM 9-5000-26)

Assume that the Y_{SL} low-power servoamplifier is not functioning. A typical LPSA is at 165 C7. The maintenance man makes a voltage check for 6.3 filament voltage and finds that it is not present at P1-14. In the block marked left rear frame, the Y_{SL} LPSA receives 6.3 volts from J244. On page 164, Distribution of Power from Bus Bars, and under rear frame, 6.3 (gnd), it reads that the 6.3 volts to J244-14 comes from E765, terminal 3(~~22C9~~). If the voltage is present here and the lead is firmly attached to terminal 3, then the trouble is between this point and the plug of the Y_{SL} LPSA. Of course, if 6.3 volts is not present at bus bar E765, then many other components will also display the same symptoms, lack of filament voltage. To trace the voltage to the source, turn to page 160, 6.3-volt A-C Distribution. Bus bar E765 is at coordinates A2. The 6.3 volts comes from transformer T18. It enters the transformer from connection 400 as 120 volts, phase C unregulated. Continuing to trace this voltage, the repairman turns to 158 D7 as indicated at A1. On page 158, power cabinet, he sees connection 851 at D7, and traces the 120 volts through terminal 851, back through F7 and F17 (D1), through the computer power switch, and out of the computer at connection 827. This 120 volts, phase C can eventually be traced all the way back to the generator. In summary the maintenance man turns to page 165 to trace an a-c trouble in a particular component of the computer. It is necessary to trace the voltage back to a jack or bus bar, shown on page 160, 161, 163, or 164, and then back to the components shown on page 158 or 159, The Power Cabinet. If need be, the repairman can continue to trace the voltage to the generator itself.

Section II. D-C POWER DISTRIBUTION

123. GENERAL

The tracing of d-c power through the computer is not a difficult problem, once the student learns to use the pages listed in table III. This knowledge, with enough practical experience, will make the student's task a very easy one.

128. POWER AND MISCELLANEOUS CONNECTIONS TO COMPONENTS (page 165 of TM 9-5000-26)

This page shows the input terminals of the relay panels, DC amplifiers, low-power servoamplifiers, zero set amplifiers, and modulators. Each pin of each block has the input labeled. DC amplifiers, LPS amplifiers, modulators, and zero set amplifiers have the same voltage on their respective input pins, but the jack numbers on each chassis are different. These various jack numbers can be seen to the left of the blocks indicating typical components. For example, at coordinates B7 is a triangle representing a typical DC amplifier. With the exception of the input signal every DC amplifier has the same voltages entering the component on the same numbered pins, but the jack to each amplifier has its own number. The jack to the CA and TA amplifier chassis is J41, the jack to the G_Y and G_P amplifier is J141, etc. The modulators, low-power servoamplifiers, zero set, and relay amplifiers are represented in the same way.

129. VOLTAGE TRACING EXAMPLE (TM 9-5000-26)

A typical LPSA is shown on page 165 C7. Plus 250 volts enters all low-power servoamplifiers on pin P1-8. To trace +250 volts to the source from the Y_{SL} LPSA begin at P1-8. To the left of the block on the box labeled rear frame left (C5), is the Y_{SL} jack, J244. The voltage enters the Y_{SL} LPSA from pin 8 of J244. There are several choices as to the page from which the +250 volts comes; page 162, d-c distribution; pages 163 and 164, distribution from bus bars; or pages 158 and 159, power cabinet distribution, all in TM 9-5000-26. Only experience will save the maintenance man from examining each page for an indication of the distribution point of the voltage. It happens, in this particular case, that the +250 volts to the Y_{SL} LPSA jack, J244, comes from a bus bar. At 164 A1 is bus bar E760, a distribution point for +250 volts. In the column opposite terminal 3 is J244-8, so terminal 3, E760 is the correct tie point in tracing +250 volts from the Y_{SL} LPSA to the source. In the power cabinet (159 B6) is bus bar E760, which is enclosed in the block labeled AMPLIFIER CABINET, so E760 on page 159, is the same bus bar. The terminals on which the +250 volts correction signal enters the amplifier cabinet, terminal 128, and leaves the power cabinet, terminal 933, are also shown (159 B5). It can be seen by tracing to the left that the +250 volts originates in the +250-volt regulator. Similarly, all other voltages can be traced back from the individual components to the computer power cabinet. Practical work follows this conference to give the student an opportunity to use the d-c power distribution sheets and to locate the components which have been discussed.

which +250 volts is distributed are indicated in the other columns. In the right hand column marked NOTES are numbers that refer to other distribution points in the computer. These numbers are tabulated at coordinates 164A7 in the NOTES box.

127. D-C DISTRIBUTION (page 162 of TM 9-5000-26)

The d-c inputs from pages 158 and 159 are at the far left of the page. Beginning at the top of the page, coordinates A1, each voltage is discussed below:

a. Minus 320-volt A enters terminal 125 and is sent to several bus bars.

b. Minus 320-volt B enters terminal 126 and is sent to bus bar E559.

c. Plus 75 volts enters terminal 121 and is sent to various bus bars.

d. Plus 320-volt A enters terminal 118 and is sent to a number of plugs and jacks.

e. Plus 320-volt B enters terminal 119 and is sent to various jacks.

f. C ground (circuit ground) is present on terminals 117 and 25, (B1).

g. Minus 28 volts enters terminal 111 (B1) and is sent to many plugs, relays, and chassis.

h. Relay ground (C1) is distributed to plugs and pins.

i. Plus 270 volts enters terminal 405, and is sent to 12 different jacks.

j. The ground for +270 volts goes to the same jacks but different pins.

k. Plus 250 volts is carefully regulated. It enters terminal 120 (C1) and is sent to the event recorder and to bus bar E760. From there, +250 volts goes to various plugs, bus bars, and pins.

l. Minus 250 volts enters terminal 124 and is sent to bus bar E768. The voltage is then distributed to plugs, bus bars, and most important, to the +S regulator. This regulator (D4, D5) puts out +106.667 volts which is used in the computer to indicate range very accurately. (The +S regulator is discussed in section VI.) At coordinates 6 and 7 are the plugs that carry +250 and -250 volts to the plotting boards and to the servo cabinet.

Section IV. OPERATION

135. GENERAL (TM 9-5000-26)

Regulator chassis used in Nike I Systems are provided with external strappings as shown schematically in TM 9-5000-26. Connecting the regulators as shown in the individual schematics makes different outputs from a standardized chassis possible.

136. VOLTAGE REGULATOR D153845 (-200 VOLTS)

The shunt voltage regulator shown schematically on page 168 is used in the computer power cabinet. The regulator consists of an input amplifier, V1, which controls the two parallel regulator pentodes, V2 and V3. The inputs are a regulated -250-volt d-c reference voltage from the plus and minus 250-volt voltage regulator and a regulated -320-volt input from the plus or minus 320 volt supply. The input to the grid of V1 is furnished by a voltage divider (R1 and R2) which is connected between the -200-volt output and the -320-volt input. The cathode of V1 is fixed at -250 volts by the regulated reference voltage input. Assume that the magnitude of the negative voltage at P1-6 drops to -199 volts because of a sudden load change. The grid of V1 would become less negative, thus causing the plate current to increase and the plate voltage to drop to a more negative potential. This voltage change is coupled to the grids of V2 and V3 by C3, R7, and R3. This increase in grid bias increases the resistances of both tubes and the voltage drop across V2 and V3 until the output voltage is restored to -200 volts. If the output at P1-6 jumps suddently to -201 volts, the regulator action is the opposite of that just described. If the voltage regulator output at P1-6 is not 200 volts, the chassis should be replaced. Accordingly, note 2 on page 168 can be deleted, because this adjustment is the responsibility of ordnance and not of the battery maintenance men. The inputs to this voltage regulator are regulated -250- and -320-volt potentials. The output is a well regulated -200 volts. This carefully controlled voltage is used as the negative d-c level for filaments of various tubes of the computer. It is also used in all DC amplifiers and in the -200-volt regulator itself.

137. VOLTAGE REGULATOR GS15548 (±250 VOLTS) (TM 9-5000-26)

This regulator, shown schematically on page 172, is located in the computer. The two output voltages, +250 volts and -250 volts, are well regulated and are closely matched in magnitude. An automatic zero setting mechanism is used to make sure that the positive and negative outputs are

Section III. D-C VOLTAGE REGULATORS

130. GENERAL

The regulation of the voltages used in the computer is, in many instances, extremely important. For that reason, it is imperative that the maintenance man know the operation and function of each voltage regulator. The computer uses the following regulated voltages: ±320 volts, ±250 volts, -200 volts, and +75 volts d-c; and 120-volt, 400-cycle a-c. The ±320-volt regulator will be studied along with radar power supplies. Both series and shunt voltage regulators are used in the Nike system. A series regulator is a variable voltage divider whose regulating element is in series with the load. A shunt regulator has its regulating element in parallel with the load. The dropping resistor of the variable voltage divider is in series with the load.

131. VOLTAGE REGULATOR D153845 (-200 VOLTS)

This regulator is a shunt type regulator, using ~~+320~~ and -250-volt inputs and producing a -200-volt output. Two of these regulators are necessary for the operation of the computer.

132. VOLTAGE REGULATOR GS15548 (±250 VOLTS)

This regulator has been specifically designed for the Nike I computer. It uses regulated plus and minus 320-volt inputs and produces plus and minus 250-volt outputs, which are extremely well matched in magnitude. This regulator uses precision resistors and an automatic zero setting mechanism for final matching of magnitudes.

133. +75-VOLT REGULATOR GS15716

This regulator is a series type regulator. It uses regulated +320-volt and -250-volt inputs and produces a +75-volt output.

134. A-C VOLTAGE REGULATOR GS50810

This regulator provides a regulated 120-volt a-c input to the computer to prevent fluctuations of input power. These fluctuations would affect filament transformer secondaries, balanced modulators, and other critical components. Phase C to neutral is the voltage regulated by this regulator.

138. VOLTAGE REGULATOR GS15716 (+75 volts)(TM 9-5000-26)

The regulator shown schematically on page 170 is a series type regulator used in the computer to produce the regulated +75-volt potential required by the computer. It uses +320-volt and -250-volt regulated potentials as inputs. Current passing through the load passes through regulator tube V1 to the +320-volt input. Tube resistance of V1 is varied by its grid potential to maintain a 75-volt drop across its load. The grid level of V1 is established by the operation of V2. The grid of tube V2 is tied to a voltage divider between +75 volts and -250 volts. If the load were to change, causing the +75-volt level to drop, the grid of V2 would drop. This would cause a decrease of plate current and a rise in plate voltage. The plate of V2 is tied to the grid of V1. The rise in plate voltage of V2 would cause V1 to increase conduction and cause the drop across the load to increase back to 75 volts. Thus 75 volts will always be dropped across the load.

Section V. A-C REGULATOR GA50810 (120-volt, 400-cycle a-c)

139. GENERAL (TM 9-5000-26)

This regulator, found schematically on page ~~170~~ regulates the 120-volt, phase C to neutral, 400-cycle a-c input to the computer, for use in circuits where a variation in a-c input power might affect the computer solution and output signals. The regulator consists of two systems of regulations in series, so arranged that the output of the circuit is regulated 120-volt, 400-cycle a-c. A ferro-resonant circuit and a saturable reactor make up the regulator.

140. FERRO-RESONANT CIRCUIT

A ferro-resonant circuit uses iron core transformers to oppose input changes; that is, if the input to the transformer should change, the output will remain relatively constant. The components of the ferro-resonant circuit include transformers T1 and T2 and capacitors C1 and C2. The output of this circuit is a somewhat regulated stepped-up voltage. This output is applied through a circuit including inductor L1, capacitors C3 and C4, and resistors R1 ~~and R2,~~ to transformer T3. This circuit tends to eliminate undesirable harmonics.

141. SATURABLE REACTOR CIRCUIT

This circuit consists of transformer T3, resistors ~~R3~~, R4, R5, ~~R6, and R7~~, a thermistor, and bridge-type, full-wave, selenium rectifier RV1. This rectifier is placed between the output terminals of the unit producing a d-c output

perfectly matched. This is necessary to obtain the required accuracy of the computer output. The inputs to the regulator are the positive and negative 320-volt regulated outputs from power supply D153848, strapping A. The -250-volt regulator is a shunt type regulator and the +250-volt regulator is a series type regulator whose output is the same magnitude as the -250-volt output. It is held at that level by the automatic zero setting mechanism. For a -250-volt output, the current flow from +320 volts, through R28, part of R26, V7, R24, and R29 to ground, establishes the cathode potential of regulator tube V7 at -250 volts. The screen grid of V5 is held at -109 volts and the suppressor grid and cathode are held at -218 volts by VR tubes V4 and B6. Therefore, the conduction of V5 will be a function of the control grid potential only if the load changes, causing the output of the regulator to become smaller (less negative), the control grid of V5 would become more positive, because of the voltage divider action of R16 and R17 from -250 volts to ground. This causes the conduction of V5 to increase, decreasing the plate potential. This decrease is coupled directly to the grid of regulator tube V7, decreasing its conduction. This causes the cathode to go more negative, causing the output to be nearer 250 volts. If the output should become more negative, the converse of the above is true. Resistor R26 is factory adjusted to establish the output at -250 volts. The current flow through the load and series regulator tubes, V3A and V3B, to -320 volts established the voltage drop across the load at +250 volts, the other output of this regulator. The grid of V1A is normally held at zero by a voltage divider from -250 volts through 100-ohm resistor R297, +250-volt network, and 200-ohm potentiometer R296 to +250 volts. This network may be seen schematically on page 160 of 2y. It is located in the lower left hand corner of the amplifier bay shown on page 5. The 200-ohm potentiometer is factory adjusted to establish 0 volts at the grids of V1, when the +250-volt output has the same magnitude as the -250 volt output. If the +250-volt output should rise, grid 3 of V1A would rise, causing the cathode to rise, and thus reduce current flow through V1B. At the same time, the rise is amplified and inverted by the automatic zero setting amplifier and applied to grid 6 of V1B as a drop, which will also decrease conduction in V1B. This decrease in conduction causes an increase of plate potential, which is coupled directly to the grid of V2. This produces an increase in plate conduction, decreasing the plate potential. This drop is applied to regulator tubes V3A and V3B, causing their cathode potential to drop and thus the +250-volt output returns to its correct value. The automatic zero setting mechanism permits extremely rapid and accurate correction of the +250-volt output. If the +250-volt output were to drop, the converse of the above discussion applies.

When the -250 volts is applied at the input, the output voltage can then be determined by multiplying the input voltage by the gain and inverting the sign. Thus, -250 volts x 0.42666 gives +106-2/3 volts output. If the load resistance of the +S voltage regulator decreases, the voltage on the cathode of V20 will decrease. This will cause the feedback voltage to become less positive and the input voltage at the grid of the DC amplifier to become more negative, increasing current flow through V20 and increasing the voltage at its cathode to the proper value.

144. DETAILED CIRCUIT FUNCTIONING

The -250-volt input applied at terminal 3 of the input network comes from the ±250-volt regulator through contacts of relay K2 on the relay and limiter panel. When K2 (162D3) is energized by the ZERO CHECK switch, ground is applied to the +S amplifier for zero checking the amplifier. At 162D6 the connection to the ZERO CHECK meter is labeled 16A4. Capacitor C20 (162D5), connected from grid to cathode of V20, prevents high-frequency oscillations from developing. The 1,000-ohm resistors in the grid leads of V20 limit grid current and prevent parasitic oscillations. The +S voltage output to the second-per-second bias network is shown at 24D6. The output to potentiometer cards TC-14B and TF-6 in the time-to-intercept servo is at terminal 237 (162D7).

which is proportional to the a-c output voltage. This d-c signal is applied to the secondary of transformer T3. The primary of the transformer is wired as an autotransformer, receiving the input from the ferro-resonant circuit and producing the output of the unit. The amplitude of the d-c input to the secondary of the transformer controls the amplitude of the a-c output by causing the transformer to approach d-c saturation. If the a-c output tends to rise, the d-c input to the transformer rises, reducing the a-c output. Thus, the output of a-c regulator GA50810 is regulated 120-volt, 400-cycle a-c.

Section VI. +S VOLTAGE REGULATOR

142. GENERAL

The +S voltage regulator establishes and maintains the scale factor voltage (+S) used by the computer with great accuracy. The +S voltage regulator is composed of a DC amplifier, a special input network, and a regulator stage including V20. The entire +S regulator is located on the left equipment frame in the computer amplifier cabinet. Tube V20 is mounted on the equipment frame directly above the +S amplifier. Power requirements, exclusive of the normal power requirements of a DC amplifier are: -250 volts from the ±250-volt regulator to the input network of the DC amplifier, and +320 volts and -320 volts to V20. The regulated 106-2/3 volts in the output is applied to the target and missile range data potentiometers, to the potentiometers in the time-to-intercept servo that are used to obtain a voltage analogous to time to intercept, and to the second-per-second bias network in the velocity feedback loop of the time-to-intercept servo.

143. SIMPLIFIED FUNCTIONAL OPERATION (page 162 D7 of TM 9-5000-26)

To maintain its required accuracy, the +S voltage regulator must have high gain. This requirement is best fulfilled by a DC amplifier. The total load on the +S regulator is approximately 10,000 ohms. The output stage of the DC amplifier cannot deliver enough power to this load. Therefore, a series regulator stage using V20 (12AU7) as a cathode follower is connected to the output of the DC amplifier. The DC amplifier acts as a preamplifier for the regulator tube. The precision input and feedback resistors of the regulator are in an oven to make sure that ambient temperature changes will not affect the output voltage. The feedback voltage is taken at the cathode of V20. If the gain of V20 is assumed to be 1, the over-all gain of the DC amplifier is:

$$\frac{R_B}{R_{in}} = \frac{0.42666 \text{ megohms}}{1.00000 \text{ megohms}} = 0.42666. \qquad (17)$$

Symbol	Definition
$\dot{H}$	Vertical component of actual closing velocity between the target and the missile.
H-distance	Vertical distance between missile and target.
H_B	Altitude of the center of the constant time circle.
H_G	Gyro coordinate vertical axis.
$\dot{H}_{GM}$	Component of missile velocity along the gryo H-axis.
H_I	Altitude of the predicted intercept point above the designated launcher.
H_L	Vertical component of launcher parallax.
H_M	Vertical distance between missile and MTR.
$\dot{H}_M$	Vertical component of missile velocity.
$\dot{H}_P$	Vertical component of target velocity during the pre-launch phase.
H_R	Vertical component of radar parallax from MTR to TTR.
H_{SL}	H-stylus left.
H_{SR}	H-stylus right.
$\frac{H}{t}$	Vertical component of ideal closing velocity between missile and target.
H_T	Vertical distance between target and TTR.
$\dot{H}_T$	Vertical component of target velocity during the steering phase.
L_i	Line of intersection; the line of intersection between the gyro reference plane and the missile velocity slant plane.
P	Pitch.

APPENDIX

SYMBOLS AND ABBREVIATIONS

Section I. SYMBOLS

Symbol	Definition
A	Azimuth.
A_G	Gyro azimuth.
A_L	Launcher azimuth.
A_M	Missile azimuth.
A_T	Target azimuth.
B	Ballistic elevation angle.
D	Slant range.
D_B	Slant range for ballistic circle or radius of constant time circle.
D_M	Missile slant range.
D_T	Target slant range.
E	Angular height.
E_M	Missile angular height.
E_T	Target angular height.
g	Gravity.
G_P	Order transmitted to the missile pitch fin.
G_Y	Order transmitted to the missile yaw fin.
H-axis	Altitude axis.

Symbol	Definition
t_{SLR}	Time stylus left and right.
V_i	Component of missile velocity along the line of intersection (the terms Q_i and SGPS have also been used to symbolize this vector).
V_M	Missile velocity.
X-axis	Earth east-west axis.
$\dot{X}$	East-west component of actual closing velocity between the target and the missile.
X-distance	East-west distance between target and missile.
X_G	Gyro coordinate east-west axis.
X_{GM}	Distance to missile measured along gyro X-axis.
$\dot{X}_{GM}$	Missile velocity component along gyro X-axis.
X_I	East-west distance to predicted intercept point from designated launcher.
X_L	East-west component of launcher parallax.
X_M	East-west distance between missile and MTR.
$\dot{X}_M$	East-west component of missile velocity.
$\dot{X}_p$	East-west component of target velocity during the prelaunch phase.
X_R	East-west component of radar parallax.
X_{SL}	X-stylus left.
X_{SR}	X-stylus right.
$\frac{X}{t}$	East-west component of ideal closing velocity between the missile and the target.

Symbol	Definition
R_B	Range to center of constant time circle.
R_G	Ground range, TTR to center of launching area.
R_I	Ground range to predicted intercept point from designated launcher.
R_M	Missile ground range from missile-tracking radar.
R_T	Target ground range from target-tracking radar.
S_C	Steering error component along missile climb axis.
S_{GH}	Steering error component along the gyro H-axis.
S_{GY}	Steering error component along the gyro Y-axis.
S_{GX}	Steering error component along the gyro X-axis.
S_i	Steering error component that lies along the line of intersection (the terms P_i and S_{GPS} have also been used to symbolize this vector).
S_{PF}	Steering error component perpendicular to the pitch fin.
S_T	Steering error component along the missile turn axis.
S_V	Steering error component along the missile velocity axis.
S_X	Steering error component along the earth X-axis.
S_Y	Steering error component along the earth Y-axis.
S_{YF}	Steering error component perpendicular to the yaw fin.
t	Time; time of flight; time to intercept.
t_d	Dead time; the period (7 seconds) timed by the dead-time unit.

Symbol	Definition
Y_T	North-south distance between target and TTR.
$\dot{Y}_T$	North-south component of target velocity during steering phase.

Section II. ABBREVIATIONS

Abbreviation	Definition
Acq	Acquisition radar.
Az	Azimuth.
BCA	Battery control area.
BCO	Battery control officer.
BCT	Battery control trailer.
BTB	Burst time bias.
CA	Climb angle.
CTA	Critical turn angle.
DTA	Difference turn angle.
El	Elevation.
IP	Predicted intercept point.
IT	Initial turn.
LC	Launching control.
LCA	Launching control area.
LCT	Launching control trailer.
Lchr	Launcher.

Symbol	Definition
X_T	East-west distance between target and TTR.
$\dot{X}_T$	East-west component of target velocity during steering phase.
Y	Yaw.
Y-axis	Earth north-south axis.
$\dot{Y}$	North-south component of actual closing velocity between the target and the missile.
Y-distance	North-south distance between target and missile.
Y_G	Gyro coordinate north-south axis.
Y_{GM}	Distance to missile measured along gyro Y-axis.
$\dot{Y}_{GM}$	Missile velocity component along gyro Y-axis.
Y_I	North-south distance to predicted intercept point from designated launcher.
Y_L	North-south component of launcher parallax.
Y_M	North-south distance between missile and MTR.
$\dot{Y}_M$	North-south component of missile velocity.
$\dot{Y}_p$	North-south component of target velocity during pre-launch phase.
Y_R	North-south component of radar parallax.
Y_{SL}	Y-stylus left.
Y_{SR}	Y-stylus right.
$\frac{Y}{t}$	North-south component of ideal closing velocity between the missile and the target.

INDEX

	Paragraph	Page
Acceleration	16	13
Actuating error	110	93
A-C power distribution	116	98
A-C distribution	118	99
Connections to components	121	100
Distribution from bus bars	120	100
Power cabinet distribution	117	98
6.3 a-c distribution	119	99
Troubleshooting	122	101
A-C regulator	139	108
Ferro-resonate circuit	140	108
Saturable-reactor circuit	141	108
A-C voltage regulator	134	105
Automatic zero setting	51	40
Block diagram	55	43
Components	54	43
Computer errors	52	40
Overload indicators	62	52
Precision zero set system	59	47
Principles of operation	53	42
Semiprecision zero set system	56	44
Azimuth potentiometer	98	85
Bus bars	120	100
Bus bar distribution	126	102
Climb angle	22	18
Command guidance	5	3
Computer servos	104	88
Controlled variable	112	94
Controller	111	94
Conversion of missile velocity	19	15
Data potentiometers	85	73
Data smoothing	46	36
Four-second data smoothing	47	36
DC amplifier	25	20
Block diagram discussion	34	25
Data smoothing	46	36

Abbreviation	Definition
M&ST	Maintenance and spares trailer.
MA	Missile away.
MSL	Mean sea level.
MTR	Missile-tracking radar.
MVSP	Missile velocity slant plane.
O Lim	Order limiting.
RCT	Radar control trailer.
Rg	Ground range.
RTF	Ready to fire.
RS	Roll stabilization.
+S	Scale factor voltage.
SAM	Surface-to-air missile.
STA	Skirting turn angle.
TA	Turn angle of the missile.
TAZ	Turn angle zero.
TDE	Target differentiator enable.
T Des	Target designate.
TGSA	Target ground speed amplifier.
TSL	Time slew.
TTR	Target-tracking radar.

	Paragraph	Page
400-cycle balanced modulator	66	55
Amplifier phase inverter	73	60
Balance network	68	56
Bridge operation, negative error signal	71	60
Bridge operation, positive error signal	70	58
Bridge operation, zero error signal	69	57
Bridge waveforms	72	60
Distortion	74	60
Simplified functional operation	67	55
Function generation	90	77
Gyro azimuth	9	8
Gyro reference plane	22	18
Horizontal plane	21	18
Input impedance	32	23
Intercept course	6	4
Inverse feedback	30	22
Isolation	31	23
Low-power servoamplifier	75	62
Bridged-T network	80	68
Paraphase amplifier	78	65
Power amplifier	79	66
Simplified functional operation	76	62
Voltage amplifiers	77	63
Missile	8	5
Missile axes	24	19
Missile velocity slant plane	23	18
Modulator	66	55
Orientation of the missile	7	5
Overload indicator	62	52
Detailed functional operation	63	52
Potentiometers (See Spiral potentiometers)	85	73
Construction of function generating potentiometers	91	79
Field practices	103	88
Load compensation	89	77

	Paragraph	Page
DC amplifier (cont)		
Detailed circuitry	35	26
Differentiation	44	34
Division	42	32
Drift compensation	33	24
Effect of increased gain	40	29
Effect of negative feedback	39	28
Feedback	38	28
Four-second data smoothing	47	36
Functions	49	39
General requirements	26	20
High-frequency compensation	37	27
Input impedance	32	23
Inverse feedback	30	22
Isolation	31	23
Multiplication	43	34
Phase shift	37	27
Polarity reversal	29	22
Power requirements	36	26
Single-stage amplifier	27	21
Specifications	50	39
Summing	41	31
Three-stage amplifier	28	21
Weighting	41	31
D-C power distribution	123	101
Bus bar distribution	126	102
Connections to components	128	104
D-C distribution	127	103
Power distribution	124	102
Tracing	129	104
-200 volts A and B	125	102
Differentiation	44	34
Drift compensation	33	24
D-C voltage regulators	130	105
-200-volt regulator	131	105
±250-volt regulator	132	105
+75-volt regulator	133	105
Elevation potentiometer	98	85
Feedback	38	28
Feedback generator	83	71
Operation	84	71

	Paragraph	Page
Servos (cont)		
Definitions	105	89
Open-loop control system	106	90
Reference input	109	92
Response	113	94
Stability	113	94
Typical applications	115	96
Use of feedback	107	90
+75-volt regulator	138	108
Single-stage DC amplifier	27	21
6.3 a-c distribution	119	99
Speed	13	12
Spherical coordinates	10	9
Military	11	9
Spiral data potentiometers (See Potentiometers)	94	81
Azimuth potentiometer	98	85
Construction	95	83
Coordinate conversion	96	83
Elevation potentiometer	98	85
Range data potentiometer	97	85
Surface-to-air missile problem	4	3
Guidance	5	3
+S voltage regulator	142	109
Detailed circuit functioning	144	110
Simplified functional operation	143	109
Tach X voltages	65	53
Three-stage DC amplifier	28	21
Turn angle	23	18
-200 volts A and B distribution	125	102
-200-volt regulator	136	106
±250-volt regulator	137	106
Vector addition and subtraction	17	14
Velocity	14	12
Rectangular components	15	13

U. S. GOVERNMENT PRINTING OFFICE : 1956 O - 387282

	Paragraph	Page
Potentiometers (cont)		
Operation	93	81
Padding	92	81
Potentiometer cards	86	73
Representation of distance or time with voltage division	87	75
Shaped potentiometer cards	90	77
Power cabinet distribution	117	98
Power connections to components	121	100
Power distribution	116	98
Precision zero set system	59	47
Detailed functional operation	60	48
Mechanical operation	61	51
Purpose	1	1
Quadrant switching	99	85
Azimuth potentiometer	100	85
Elevation potentiometer	101	86
Operation	102	86
Range data potentiometer	97	85
Rectangular components of velocity	15	13
Rectangular coordinates	12	9
Reference input	109	92
Reference planes and axes	20	17
References	2	1
Resolution of vectors	18	15
Review of the AAA problem	3	1
Semiprecision automatic zero setting system	56	44
Detailed functional operation	57	44
Mechanical operation	58	45
Servo loop elements	64	53
Servomotor	81	69
Operation	82	69
Servos	104	88
Actuating error	110	93
Auxiliary feedback loops	114	96
Basic principles	105	89
Components	108	91
Controlled variable	112	94
Controller	111	94

TECHNICAL MANUAL

NIKE I SYSTEMS NIKE I COMPUTER SAM PROBLEM ANALYSIS SERVO LOOP ELEMENTS AND POWER DISTRIBUTION (U)

TM 9-5000-13
CHANGES No. 1

DEPARTMENT OF THE ARMY
WASHINGTON 25, D. C., *17 December 1956*

TM 9-5000-13, 15 May 1956, is changed as follows:

Page	*Paragraph*	*Line*	*Changes*
13	16	8	Change "miles" to **mils.**
21	28	7	Change "To achieve a plate-to-cathode voltage of V1" to **To achieve the same plate-to-cathode voltage as V1.**
22	30	11	Add **inverse** before feedback.
26	35	14	Change "6AU5" to **6AU6.**
26	36	10	Change "6AU5" to **6AU6.**
27	37	28	Change "20kc" to **17kc.**
30	Fig. 26		Change "R_{in}=100.02V" to **E_{in}=100.02V.**
32	42	8	Change "75 volts" to **−75 volts.**
33	Fig. 31		Delete "$+E_{out}=-20\times1/1\times25/50=-10$ volts."
43	53	13	Change figure reference to **(fig. 41).**
45	57	4	Change figure reference to **figure 41.**
52	63	6 & 9	Change "C5" to **C1.**
52	63	10	After charging add **further.**
67	Fig. 56		The circuit symbol for T1 should include an iron core.
68	80	11	Add **(fig. 56)** after R21 and R22.
100	119	7	Change "C5" to **C4.**
100	119	14	Change "target and ground speed amplifier" to **target ground speed amplifier.**
100	119	15	Change "labeled" to **connected to.**
100	120	13	Change "A5" to **C13.** Change "J95" to **R296.**
101	122	6	Change "(22C9)" to **(164C9).**
103	126	3	Change "164A7" to **164B13.**
103	127i		Change "terminal 405" to **terminals 404 and 405.**
103	127l	5	Change "6 and 7" to **D6 and D-7.**
105	131	1	Change "+320" to **−320.**
105	132	Title	Change "(+250 VOLTS)" to **(±250 VOLTS).**
107	137	7	Change "±320 volts" to **−320 volts.**
107	137	11	Change "B6" to **V6.**
108	139	1	Change "page 170" to **page 173.**
108	140	6	Change "resistors R1 and R2" to **resistor R1.**
108	141	1	Change first sentence to read: **The circuit consists of transformer T3, resistors R2, R4, and R5, thermistor TH1, and bridge-type, full-wave, selenium rectifier RV1.**

[AG 413.44 (27 Nov 56)]

412015—56

WARNING NOTICES

Authority for release of this document to a foreign government must be secured from the Assistant Chief of Staff, Intelligence, Department of the Army.

When this document is released to a foreign government, it is released subject to the following conditions: This information is furnished with the understanding that it will not be released to another nation without specific approval of the United States of America, Department of the Army; that it will not be used for other than military purposes; that individual or corporation rights originating in the information whether patented or not will be respected; and that the information will be afforded substantially the same degree of security as afforded by the United States of America, Department of the Army.

This document contains information affecting the national defense of the United States within the meaning of the Espionage Laws, Title 18 U. S. C., sections 793 and 794. The transmission or the revelation of its contents in any manner to an unauthorized person is prohibited by law.